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Stirling-Gallacher et al.

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(45) **Date of Patent: Aug. 25, 2020**

(54) **SYSTEM AND METHOD FOR MILLIMETER WAVE COMMUNICATIONS**

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(73) Assignee: **Futurewei Technologies, Inc.**, Plano, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 122 days.

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(22) Filed: **Jun. 15, 2018**

(65) **Prior Publication Data**

US 2018/0310188 A1 Oct. 25, 2018

Related U.S. Application Data

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(51) **Int. Cl.**
H04W 16/28 (2009.01)
H04B 7/024 (2017.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04W 16/28*** (2013.01); ***H04B 7/024*** (2013.01); ***H04W 56/001*** (2013.01); *H04B 7/0617* (2013.01); *H04W 24/08* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,814,068 B2 11/2017 Frenne et al.
2009/0245176 A1 10/2009 Balasubramanian et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 103931109 A 7/2014
CN 104067538 A 9/2014
(Continued)

OTHER PUBLICATIONS

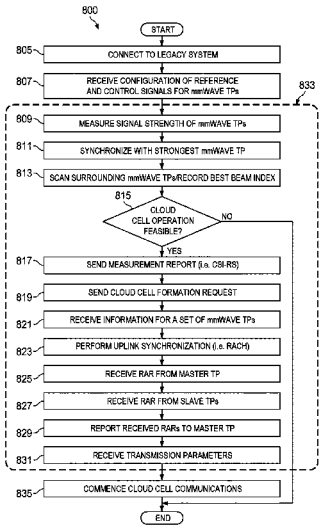
Arana, et al., "Random-Access Technique for Self-Organization of 5G Millimeter-Wave Cellular Communications," Mobile Information Systems, vol. 2016, Article ID 5261089, Aug. 7, 2016, 11 pages.
(Continued)

Primary Examiner — Rebecca E Song
(74) *Attorney, Agent, or Firm* — Slater Matsil, LLP

(57) **ABSTRACT**

A method includes measuring beam-formed reference signals transmitted by a plurality of mmWave transmission points (TPs), sending a cloud cell formation request including indicators associated with best mmWave TPs determined in accordance with the measured beam-formed reference signals, receiving a cloud cell formation request response including indicators associated with a subset of the best mmWave TPs selected by a central controller in accordance with selection information, where the subset of the best mmWave TPs includes a first mmWave transmission point (TP) serving as a master TP and a second mmWave TP serving as a slave TP, and establishing a cloud cell with mmWave TPs of the subset of the best mmWave TPs selected by the central controller, where a data connection is established with the slave TP and at least a control connection is established with the master TP.

17 Claims, 30 Drawing Sheets



(51) **Int. Cl.**

H04W 56/00	(2009.01)
H04B 7/06	(2006.01)
H04W 24/08	(2009.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0320874	A1	12/2012	Li et al.	
2013/0065622	A1	3/2013	Hwang	
2013/0195042	A1	8/2013	Taori et al.	
2013/0322367	A1*	12/2013	Kang	H04W 48/16 370/329
2013/0322375	A1*	12/2013	Chang	H04W 72/0413 370/329
2014/0010178	A1	1/2014	Yu et al.	
2014/0023040	A1	1/2014	Son et al.	
2014/0044065	A1	2/2014	Agiwal et al.	
2014/0148182	A1	5/2014	Jeong et al.	
2014/0269493	A1	9/2014	Forenza et al.	
2014/0317314	A1	10/2014	Nigam et al.	
2014/0334564	A1	11/2014	Singh et al.	
2015/0004975	A1*	1/2015	Yamamoto	H04W 36/30 455/436
2015/0173100	A1	6/2015	Aydin et al.	
2015/0181502	A1	6/2015	Hans et al.	
2015/0181601	A1	6/2015	Schmidt et al.	
2015/0351135	A1	12/2015	Schmidt et al.	
2016/0057585	A1	2/2016	Horn et al.	
2016/0057658	A1	2/2016	Horn et al.	
2016/0057687	A1	2/2016	Horn et al.	
2016/0066279	A1	3/2016	Lee et al.	
2016/0192176	A1*	6/2016	Zhu	H04W 8/005 370/329
2017/0023040	A1	1/2017	Stewart	
2017/0033904	A1	2/2017	Stirling-Gallacher et al.	
2017/0086199	A1	3/2017	Zhang et al.	
2017/0126482	A1	5/2017	Jayaraman et al.	
2017/0150363	A1	5/2017	Tenny et al.	
2017/0164348	A1	6/2017	Agiwal et al.	
2017/0195033	A1*	7/2017	Zhang	H04W 72/046
2017/0295502	A1	10/2017	Stirling-Gallacher et al.	
2017/0295508	A1	10/2017	Stirling-Gallacher et al.	
2017/0339662	A1	11/2017	Lin et al.	
2018/0249374	A1*	8/2018	Park	H04J 11/00

FOREIGN PATENT DOCUMENTS

CN	104303485	A	1/2015
CN	104335648	A	2/2015
EP	3188548	A1	9/2014
JP	2015508626	A	3/2015
JP	2015526015	A	9/2015
KR	20130087258	A	8/2013
KR	20130135696	A	12/2013
RU	2497311	C2	10/2013
WO	2015089303	A1	6/2015
WO	2016000092	A1	1/2016
WO	2016044991	A1	3/2016

OTHER PUBLICATIONS

Li, Qian (Clara), et al., "Anchor-Booster Based Heterogeneous Networks with mmWave Capable Booster Cells," 2013 IEEE Globecom Workshops (GC Wkshps), Dec. 9-13, 2013, pp. 93-98.

Taori, Rakesh, et al., "Cloud Cell: Paving the way for Edgeless Networks," 2013 IEEE Global Communications Conference (GLOBECOMM), Dec. 9-13, 2013, pp. 3546-3552.

Weiler, Richard J., et al., "Split control plane functionality in millimeter-wave overlay access," 5G for Ubiquitous Connectivity (5GU), Nov. 26-28, 2014, pp. 134-139.

* cited by examiner

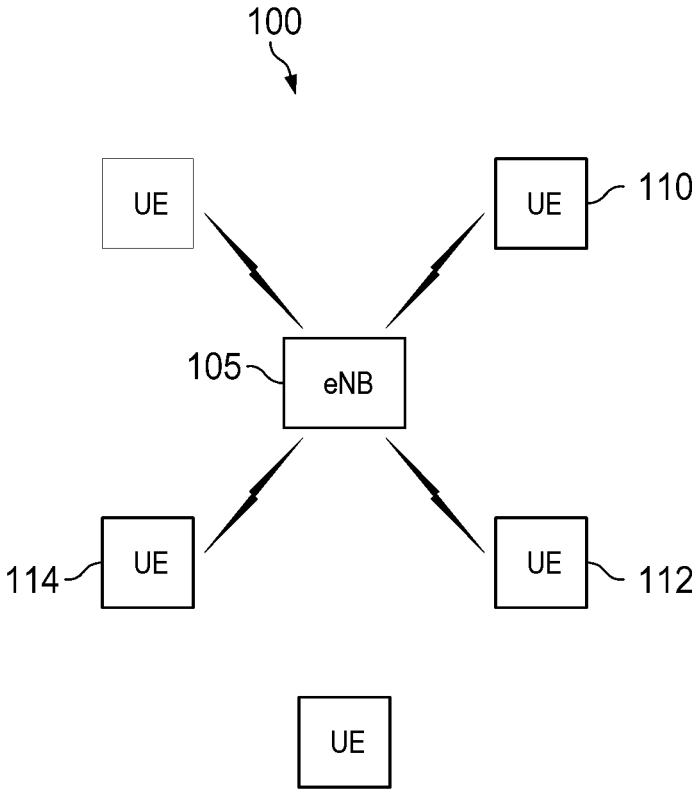


FIG. 1

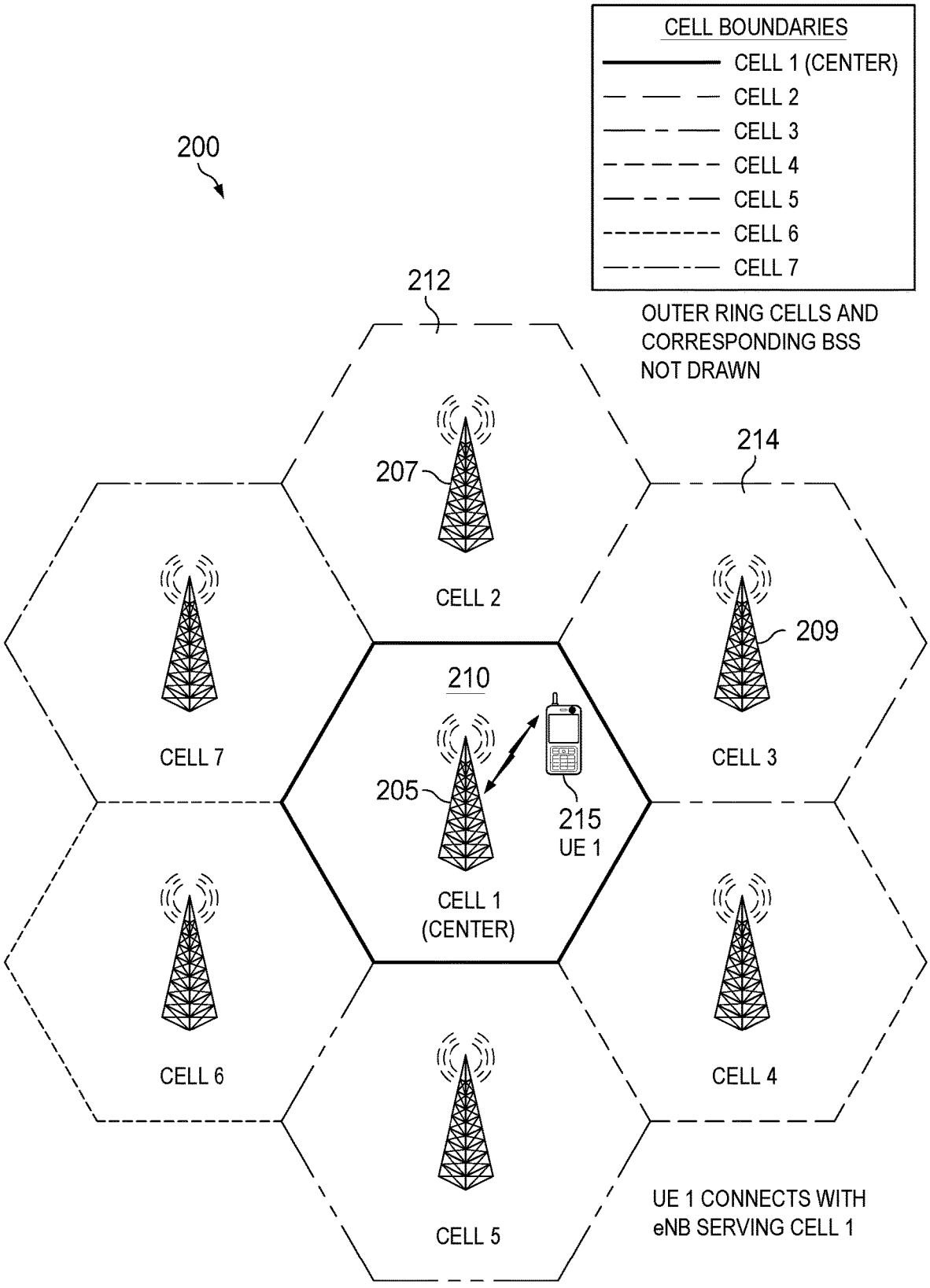

CELL BOUNDARIES
CELL 1 (CENTER)
CELL 2
CELL 3
CELL 4
CELL 5
CELL 6
CELL 7
200
212
OUTER RING CELLS AND CORRESPONDING BSS NOT DRAWN
214
207
CELL 2
209
210
CELL 7
CELL 3
205
215
UE 1
CELL 1
(CENTER)
CELL 6
CELL 4
CELL 5
UE 1 CONNECTS WITH eNB SERVING CELL 1

FIG. 2

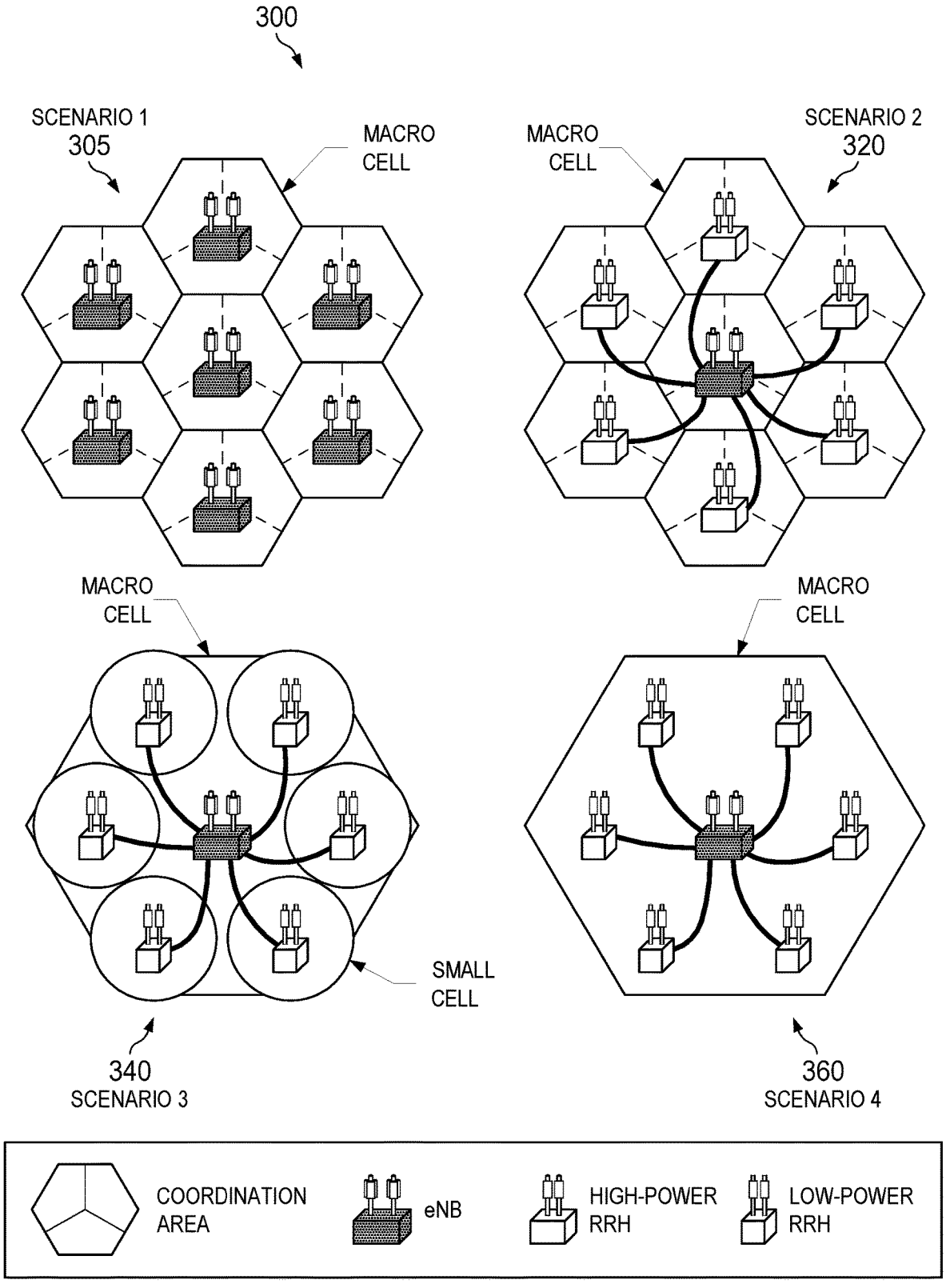
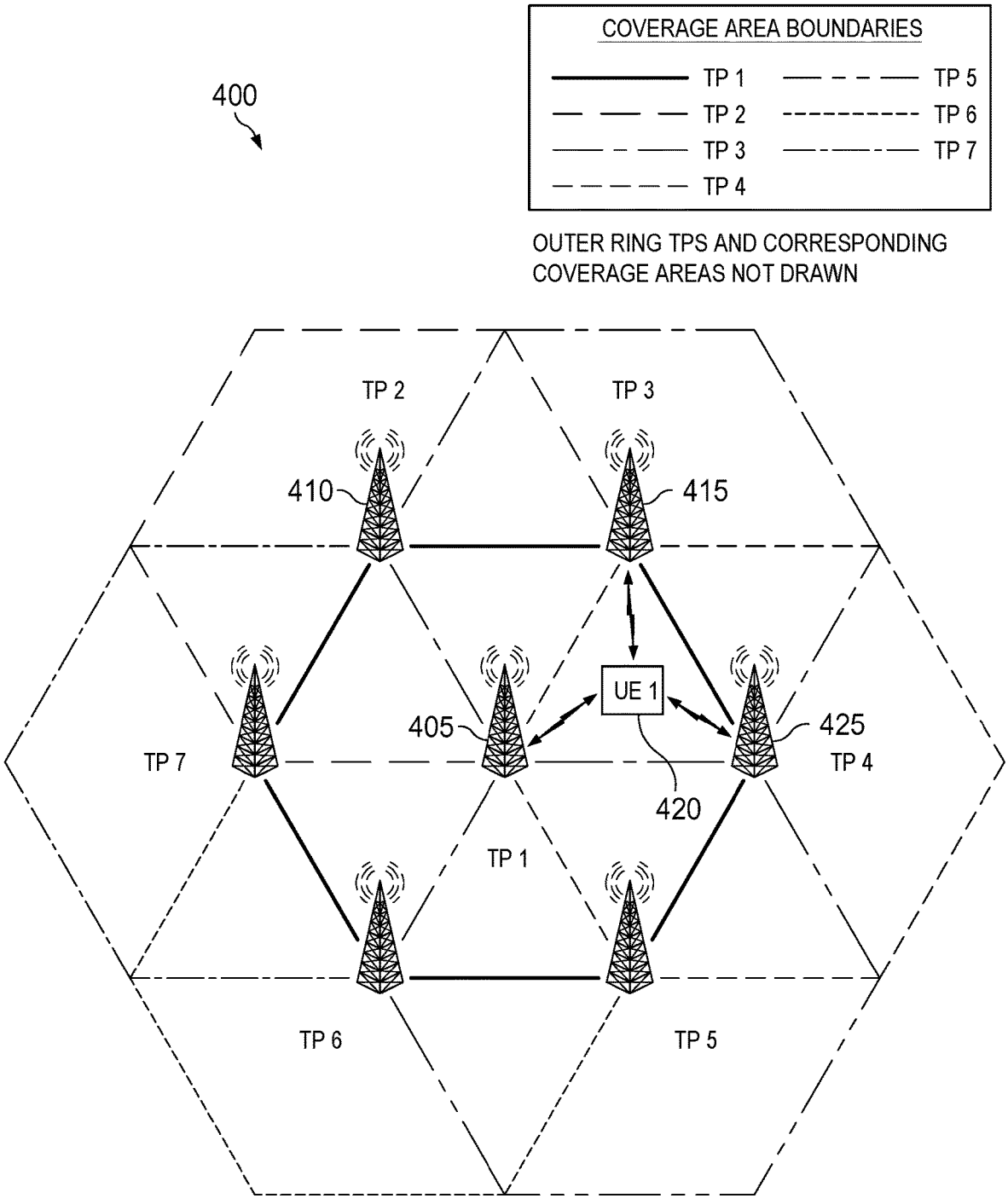

300
SCENARIO 1
305
MACRO CELL
MACRO CELL
SCENARIO 2
320
MACRO CELL
MACRO CELL
SMALL CELL
340
SCENARIO 3
360
SCENARIO 4
COORDINATION AREA
eNB
HIGH-POWER RRH
LOW-POWER RRH

FIG. 3



EXAMPLE UE 1 COULD HAVE:

1. HIGH SNR CONNECTION WITH SERVING TPs 1, 4 AND 3
2. LOW SNR CONNECTION (OUT OF COVERAGE AREA) WITH SERVING TPS 2, 5, 6, AND 7 AND OTHER TPs IN THE OUTER RING (NOT DRAWN)

FIG. 4

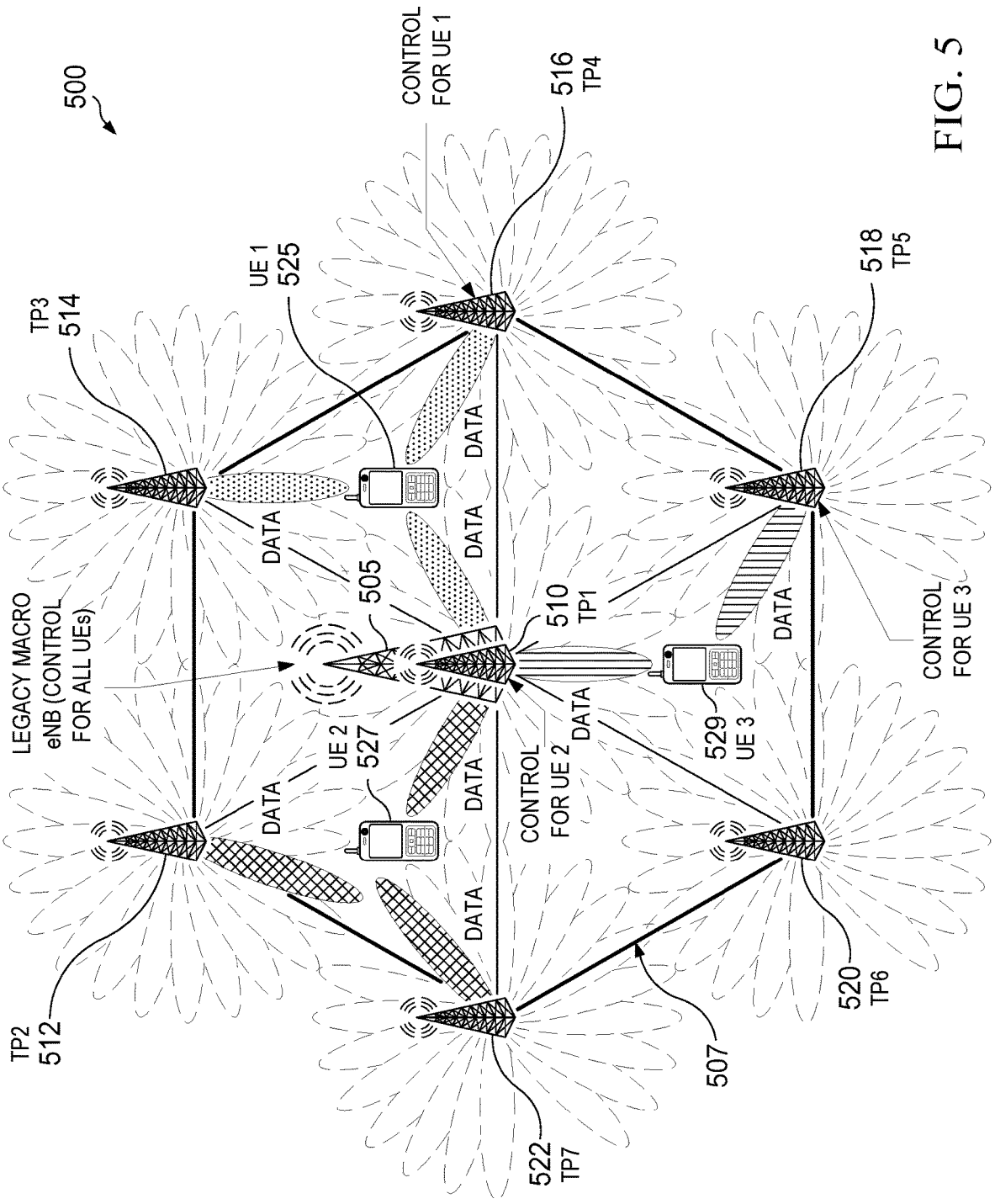

500
CONTROL FOR UE 1
516 TP4
UE 1 525
TP3 514
518 TP5
DATA
DATA
DATA
505
LEGACY MACRO eNB (CONTROL FOR ALL UEs)
510 TP1
DATA
CONTROL FOR UE 3
UE 2 527
DATA
DATA
CONTROL FOR UE 2
DATA
529 UE 3
DATA
DATA
DATA
TP2 512
520 TP6
507
522 TP7

FIG. 5

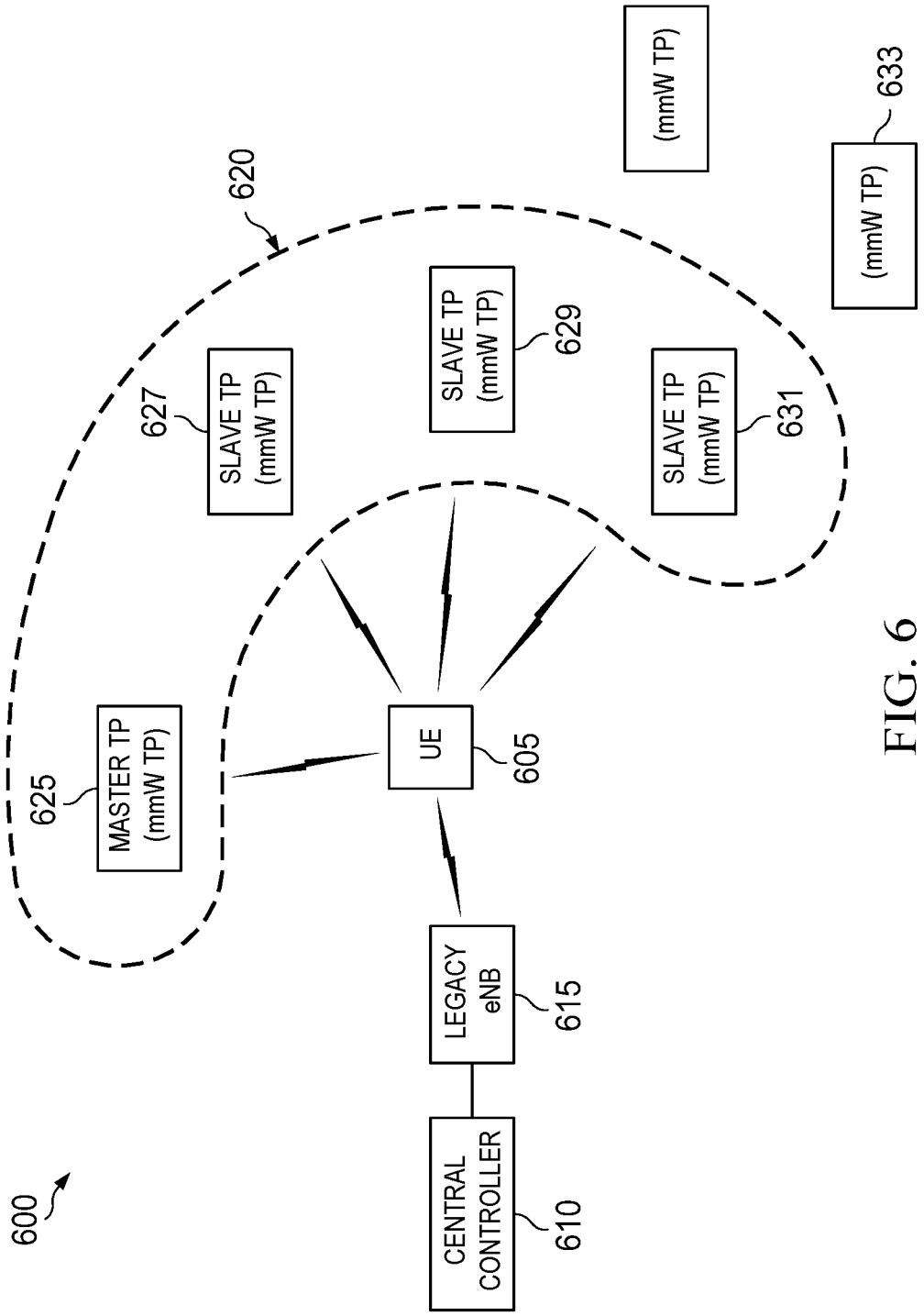

600
CENTRAL CONTROLLER
610
LEGACY eNB
615
UE
605
MASTER TP (mmW TP)
625
SLAVE TP (mmW TP)
627
SLAVE TP (mmW TP)
629
SLAVE TP (mmW TP)
631
620
(mmW TP)
(mmW TP)
633

FIG. 6

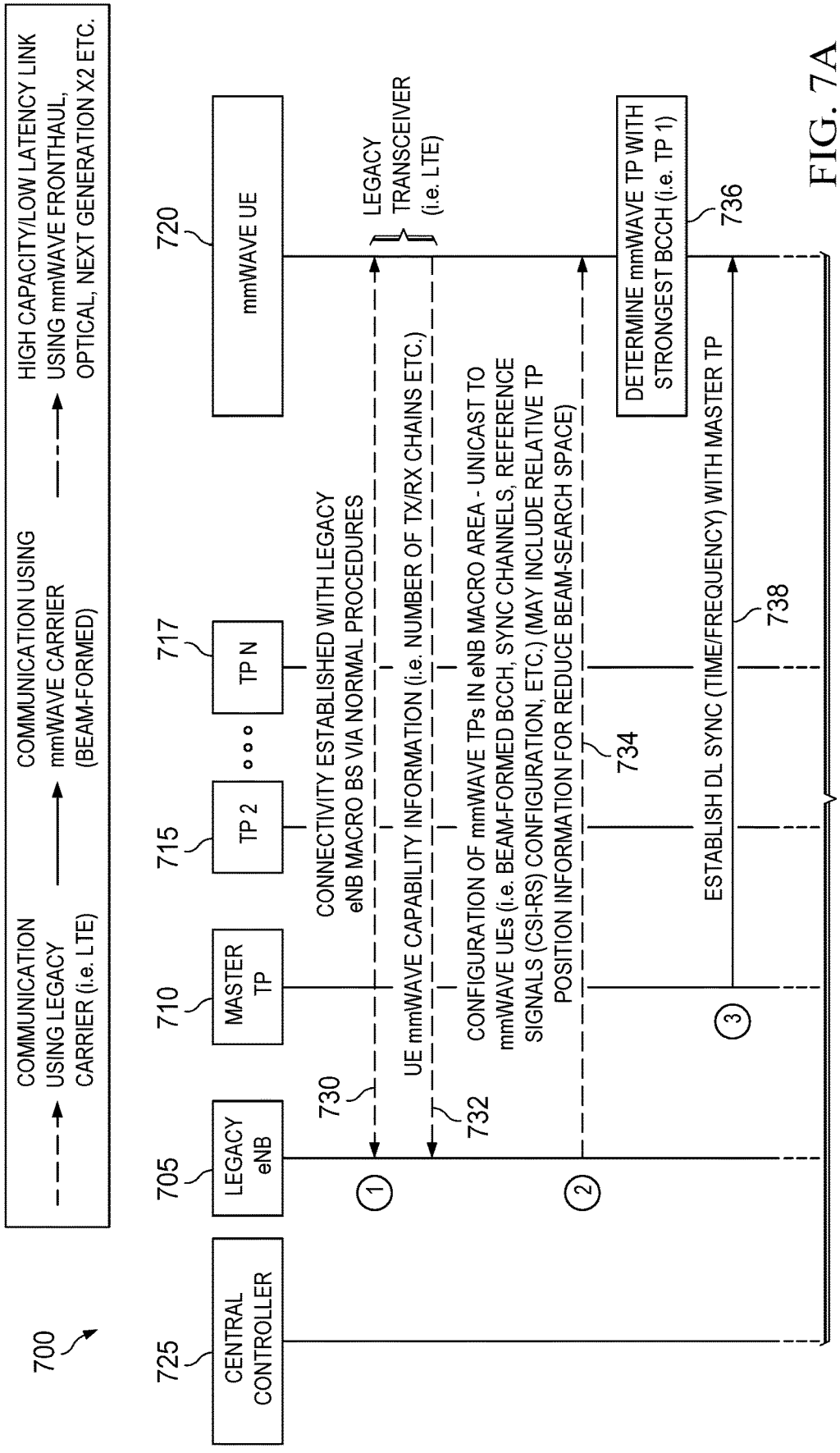

700
725
CENTRAL CONTROLLER
705
LEGACY eNB
710
MASTER TP
715
TP 2
717
TP N
720
mmWAVE UE
COMMUNICATION USING LEGACY CARRIER (i.e. LTE)
COMMUNICATION USING mmWAVE CARRIER (BEAM-FORMED)
HIGH CAPACITY/LOW LATENCY LINK USING mmWAVE FRONTHAUL, OPTICAL, NEXT GENERATION X2 ETC.
730
CONNECTIVITY ESTABLISHED WITH LEGACY eNB MACRO BS VIA NORMAL PROCEDURES
732
UE mmWAVE CAPABILITY INFORMATION (i.e. NUMBER OF TX/RX CHAINS ETC.)
LEGACY TRANSCEIVER (i.e. LTE)
734
CONFIGURATION OF mmWAVE TPs IN eNB MACRO AREA - UNICAST TO mmWAVE UEs (i.e. BEAM-FORMED BCCH, SYNC CHANNELS, REFERENCE SIGNALS (CSI-RS) CONFIGURATION, ETC.) (MAY INCLUDE RELATIVE TP POSITION INFORMATION FOR REDUCE BEAM-SEARCH SPACE)
736
DETERMINE mmWAVE TP WITH STRONGEST BCCH (i.e. TP 1)
738
ESTABLISH DL SYNC (TIME/FREQUENCY) WITH MASTER TP
1
2
3
TO FIG. 7B

FIG. 7A

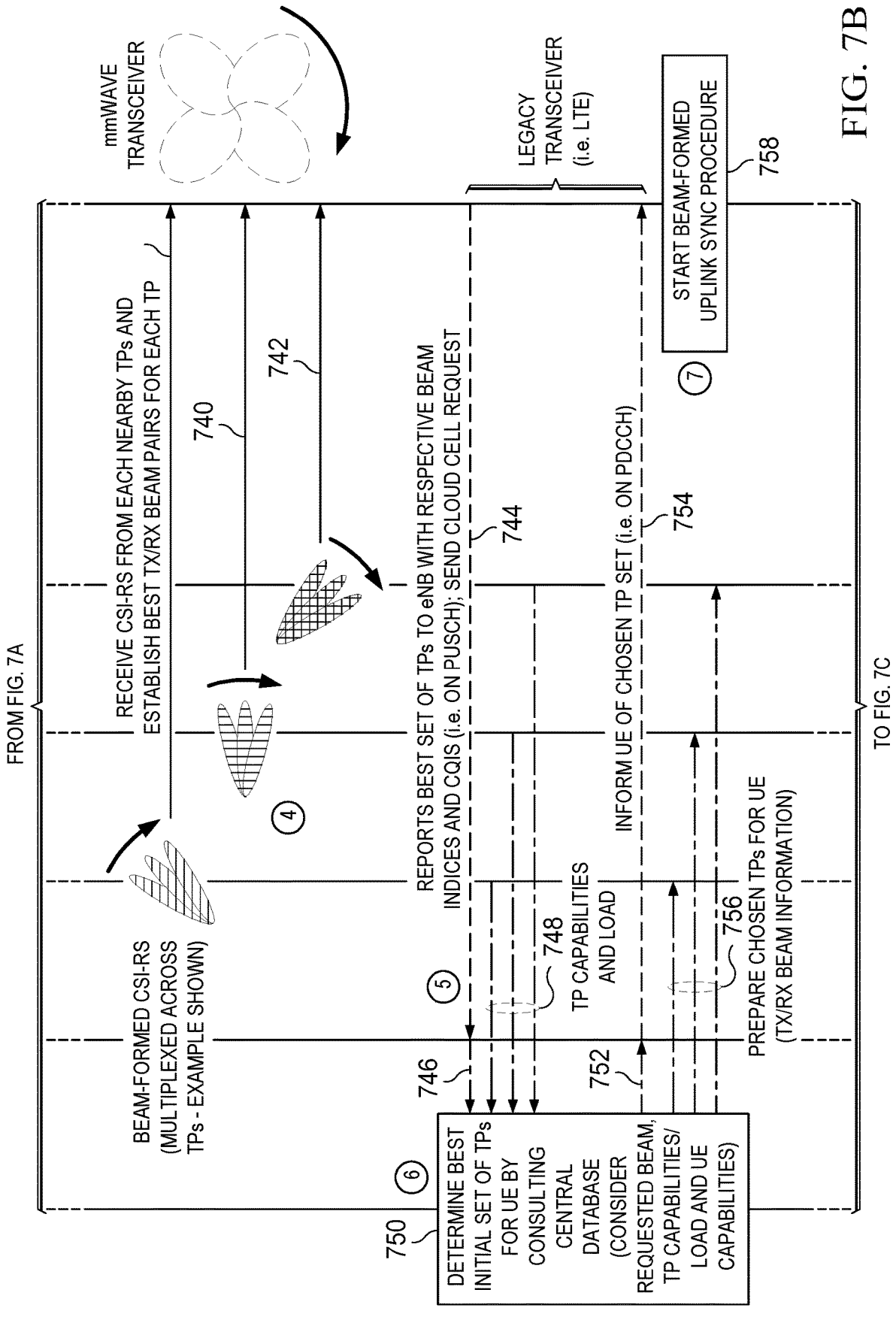

mmWAVE TRANSCEIVER
LEGACY TRANSCEIVER (i.e. LTE)
FROM FIG. 7A
TO FIG. 7C
BEAM-FORMED CSI-RS (MULTIPLEXED ACROSS TPs - EXAMPLE SHOWN)
RECEIVE CSI-RS FROM EACH NEARBY TPs AND ESTABLISH BEST TX/RX BEAM PAIRS FOR EACH TP
REPORTS BEST SET OF TPs TO eNB WITH RESPECTIVE BEAM INDICES AND CQIS (i.e. ON PUSCH); SEND CLOUD CELL REQUEST
INFORM UE OF CHOSEN TP SET (i.e. ON PDCCH)
START BEAM-FORMED UPLINK SYNC PROCEDURE
TP CAPABILITIES AND LOAD
PREPARE CHOSEN TPs FOR UE (TX/RX BEAM INFORMATION)
DETERMINE BEST INITIAL SET OF TPs FOR UE BY CONSULTING CENTRAL DATABASE (CONSIDER REQUESTED BEAM, TP CAPABILITIES/ LOAD AND UE CAPABILITIES)
740
742
744
746
748
750
752
754
756
758
4
5
6
7

FIG. 7B

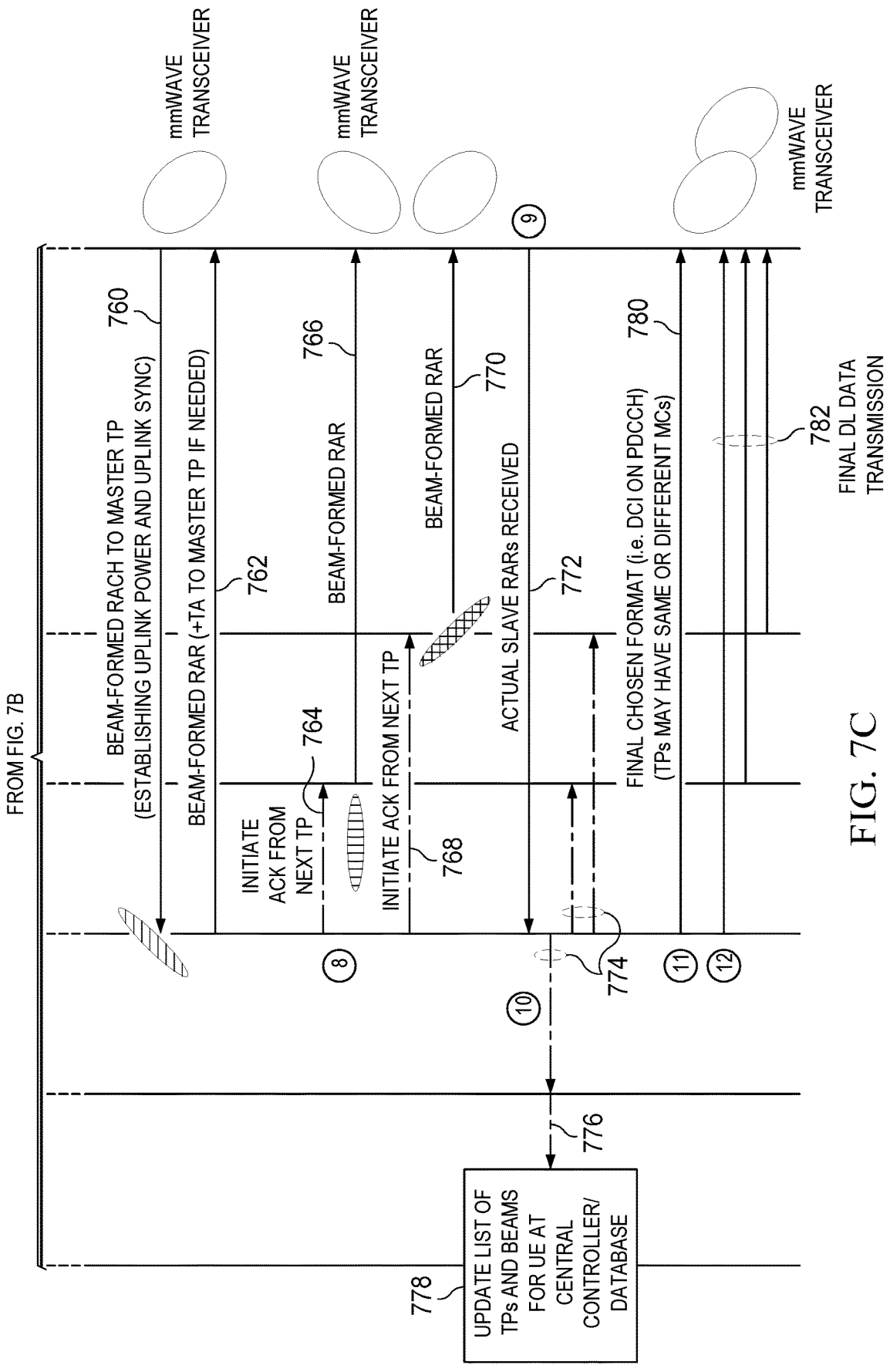

mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
FROM FIG. 7B
BEAM-FORMED RACH TO MASTER TP (ESTABLISHING UPLINK POWER AND UPLINK SYNC)
760
BEAM-FORMED RAR (+TA TO MASTER TP IF NEEDED)
762
BEAM-FORMED RAR
766
BEAM-FORMED RAR
770
ACTUAL SLAVE RARs RECEIVED
772
FINAL CHOSEN FORMAT (i.e. DCI ON PDCCH) (TPs MAY HAVE SAME OR DIFFERENT MCs)
780
782
FINAL DL DATA TRANSMISSION
INITIATE ACK FROM NEXT TP
764
INITIATE ACK FROM NEXT TP
768
774
776
UPDATE LIST OF TPs AND BEAMS FOR UE AT CENTRAL CONTROLLER/ DATABASE
778
8
9
10
11
12

FIG. 7C

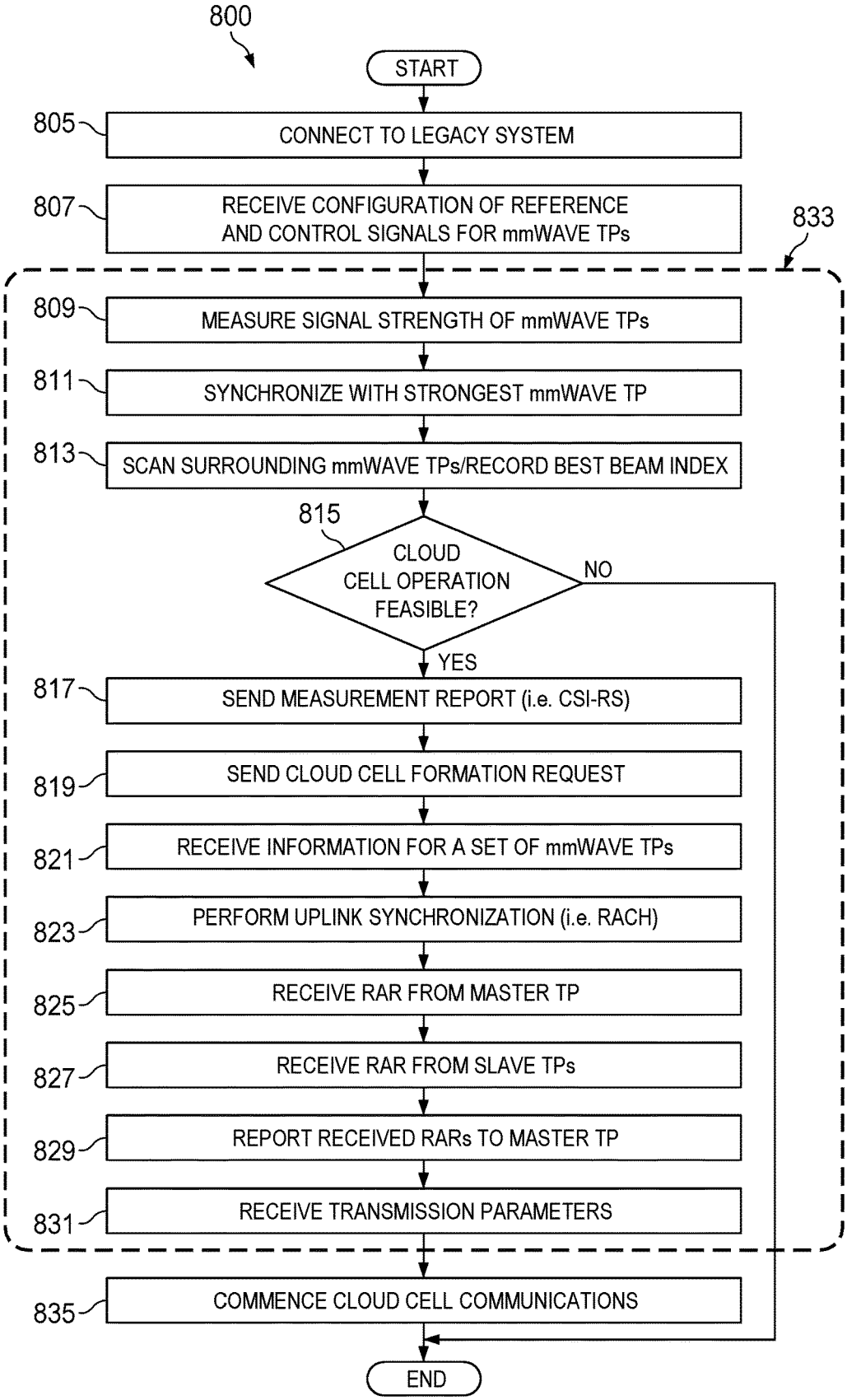

800
START
805
CONNECT TO LEGACY SYSTEM
807
RECEIVE CONFIGURATION OF REFERENCE AND CONTROL SIGNALS FOR mmWAVE TPs
833
809
MEASURE SIGNAL STRENGTH OF mmWAVE TPs
811
SYNCHRONIZE WITH STRONGEST mmWAVE TP
813
SCAN SURROUNDING mmWAVE TPs/RECORD BEST BEAM INDEX
815
CLOUD CELL OPERATION FEASIBLE?
NO
YES
817
SEND MEASUREMENT REPORT (i.e. CSI-RS)
819
SEND CLOUD CELL FORMATION REQUEST
821
RECEIVE INFORMATION FOR A SET OF mmWAVE TPs
823
PERFORM UPLINK SYNCHRONIZATION (i.e. RACH)
825
RECEIVE RAR FROM MASTER TP
827
RECEIVE RAR FROM SLAVE TPs
829
REPORT RECEIVED RARs TO MASTER TP
831
RECEIVE TRANSMISSION PARAMETERS
835
COMMENCE CLOUD CELL COMMUNICATIONS
END

FIG. 8

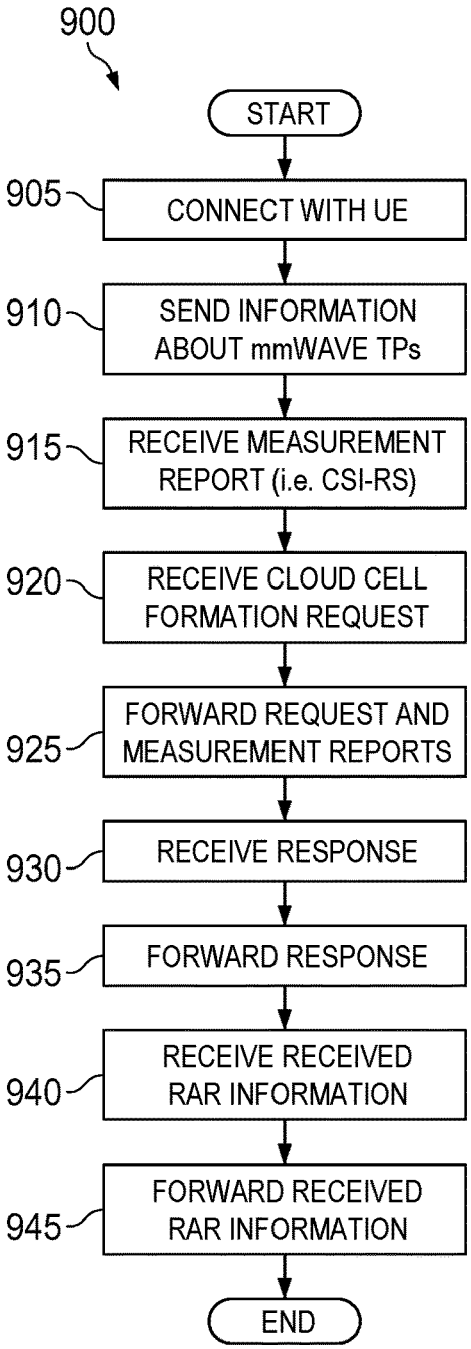

900
START
905
CONNECT WITH UE
910
SEND INFORMATION ABOUT mmWAVE TPs
915
RECEIVE MEASUREMENT REPORT (i.e. CSI-RS)
920
RECEIVE CLOUD CELL FORMATION REQUEST
925
FORWARD REQUEST AND MEASUREMENT REPORTS
930
RECEIVE RESPONSE
935
FORWARD RESPONSE
940
RECEIVE RECEIVED RAR INFORMATION
945
FORWARD RECEIVED RAR INFORMATION
END

FIG. 9

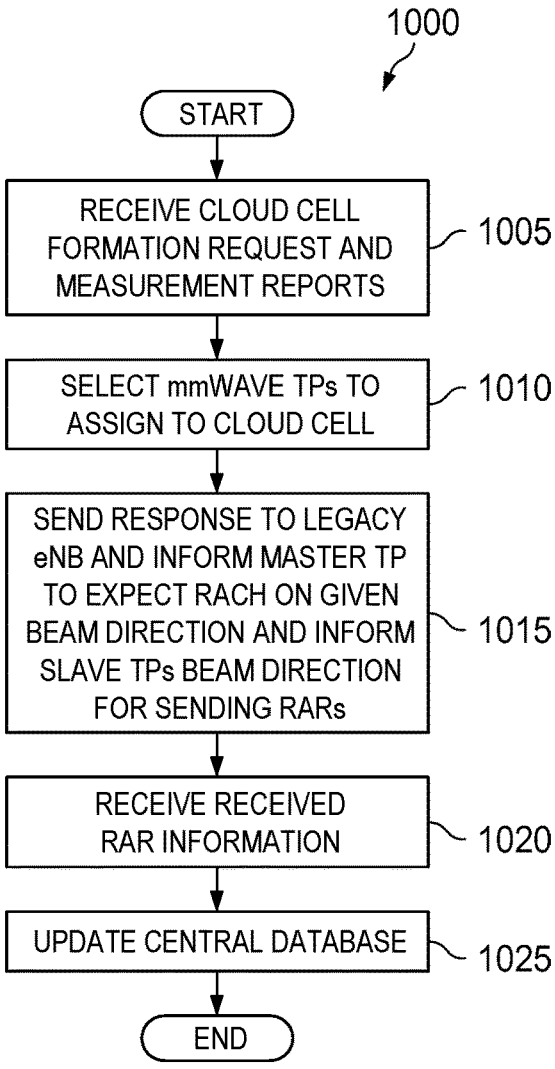

1000
START
RECEIVE CLOUD CELL FORMATION REQUEST AND MEASUREMENT REPORTS
1005
SELECT mmWAVE TPs TO ASSIGN TO CLOUD CELL
1010
SEND RESPONSE TO LEGACY eNB AND INFORM MASTER TP TO EXPECT RACH ON GIVEN BEAM DIRECTION AND INFORM SLAVE TPs BEAM DIRECTION FOR SENDING RARs
1015
RECEIVE RECEIVED RAR INFORMATION
1020
UPDATE CENTRAL DATABASE
1025
END

FIG. 10

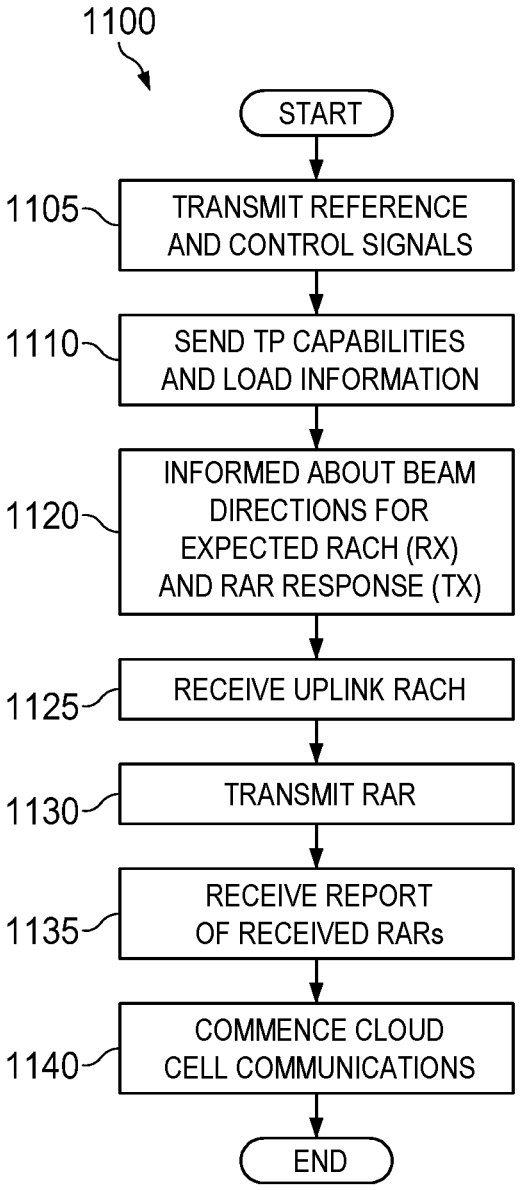

1100
START
1105
TRANSMIT REFERENCE AND CONTROL SIGNALS
1110
SEND TP CAPABILITIES AND LOAD INFORMATION
1120
INFORMED ABOUT BEAM DIRECTIONS FOR EXPECTED RACH (RX) AND RAR RESPONSE (TX)
1125
RECEIVE UPLINK RACH
1130
TRANSMIT RAR
1135
RECEIVE REPORT OF RECEIVED RARs
1140
COMMENCE CLOUD CELL COMMUNICATIONS
END

FIG. 11

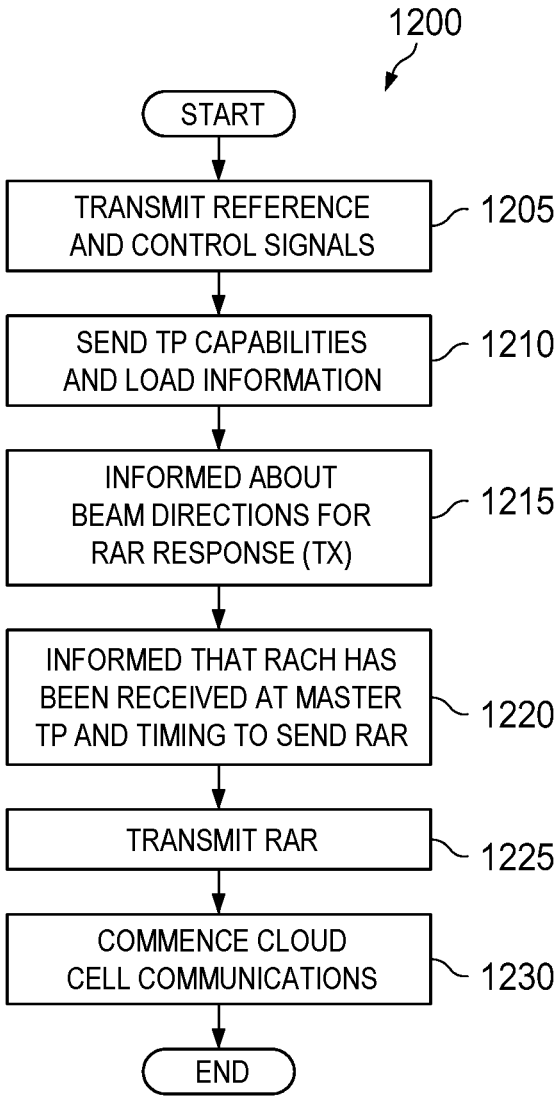

1200
START
TRANSMIT REFERENCE AND CONTROL SIGNALS
1205
SEND TP CAPABILITIES AND LOAD INFORMATION
1210
INFORMED ABOUT BEAM DIRECTIONS FOR RAR RESPONSE (TX)
1215
INFORMED THAT RACH HAS BEEN RECEIVED AT MASTER TP AND TIMING TO SEND RAR
1220
TRANSMIT RAR
1225
COMMENCE CLOUD CELL COMMUNICATIONS
1230
END

FIG. 12

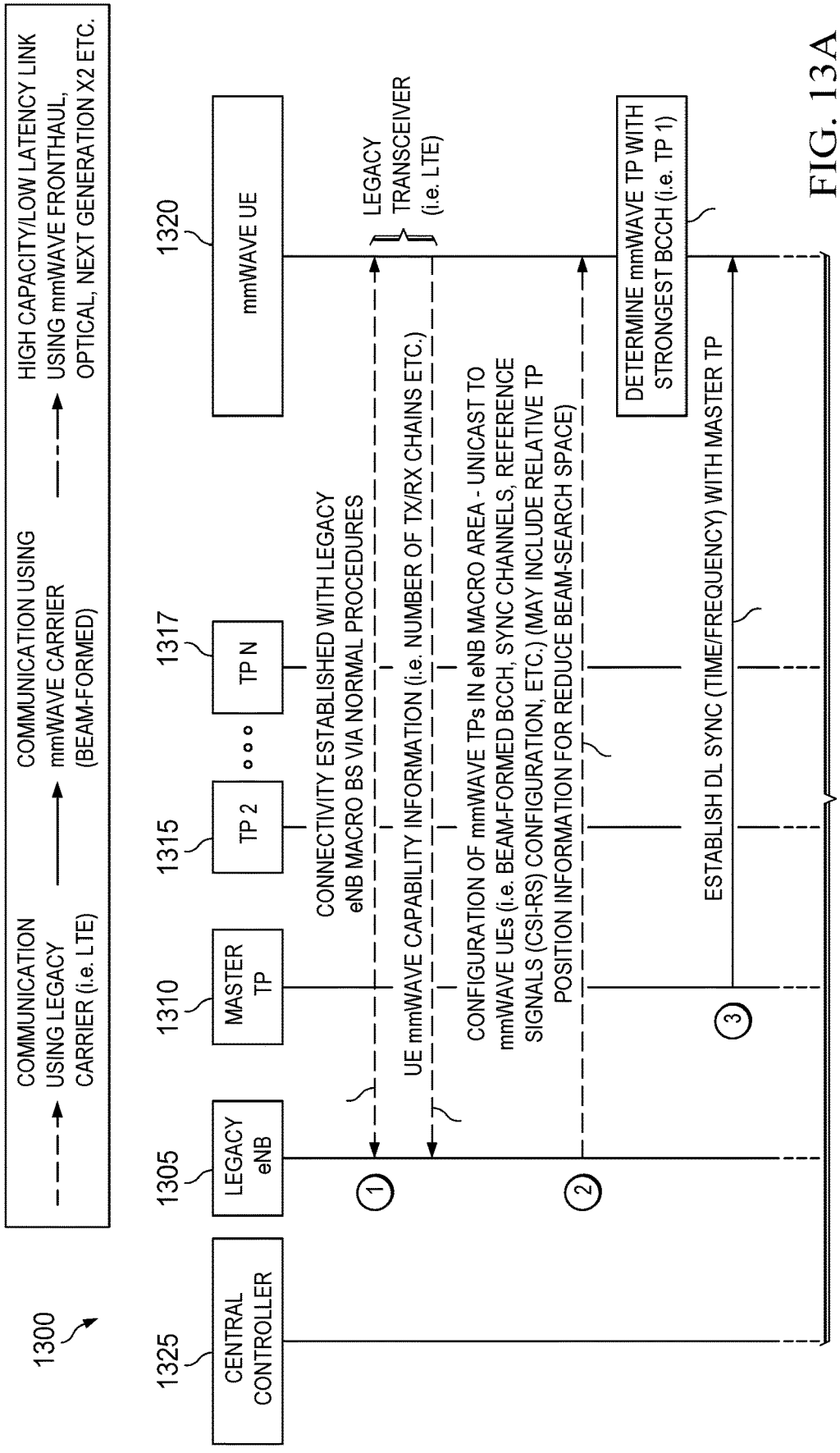

1300
COMMUNICATION USING LEGACY CARRIER (i.e. LTE)
COMMUNICATION USING mmWAVE CARRIER (BEAM-FORMED)
HIGH CAPACITY/LOW LATENCY LINK USING mmWAVE FRONTHAUL, OPTICAL, NEXT GENERATION X2 ETC.
1325
CENTRAL CONTROLLER
1305
LEGACY eNB
1310
MASTER TP
1315
TP 2
TP N
1317
1320
mmWAVE UE
LEGACY TRANSCEIVER (i.e. LTE)
CONNECTIVITY ESTABLISHED WITH LEGACY eNB MACRO BS VIA NORMAL PROCEDURES
UE mmWAVE CAPABILITY INFORMATION (i.e. NUMBER OF TX/RX CHAINS ETC.)
CONFIGURATION OF mmWAVE TPs IN eNB MACRO AREA - UNICAST TO mmWAVE UEs (i.e. BEAM-FORMED BCCH, SYNC CHANNELS, REFERENCE SIGNALS (CSI-RS) CONFIGURATION, ETC.) (MAY INCLUDE RELATIVE TP POSITION INFORMATION FOR REDUCE BEAM-SEARCH SPACE)
DETERMINE mmWAVE TP WITH STRONGEST BCCH (i.e. TP 1)
ESTABLISH DL SYNC (TIME/FREQUENCY) WITH MASTER TP
1
2
3
TO FIG. 13B

FIG. 13A

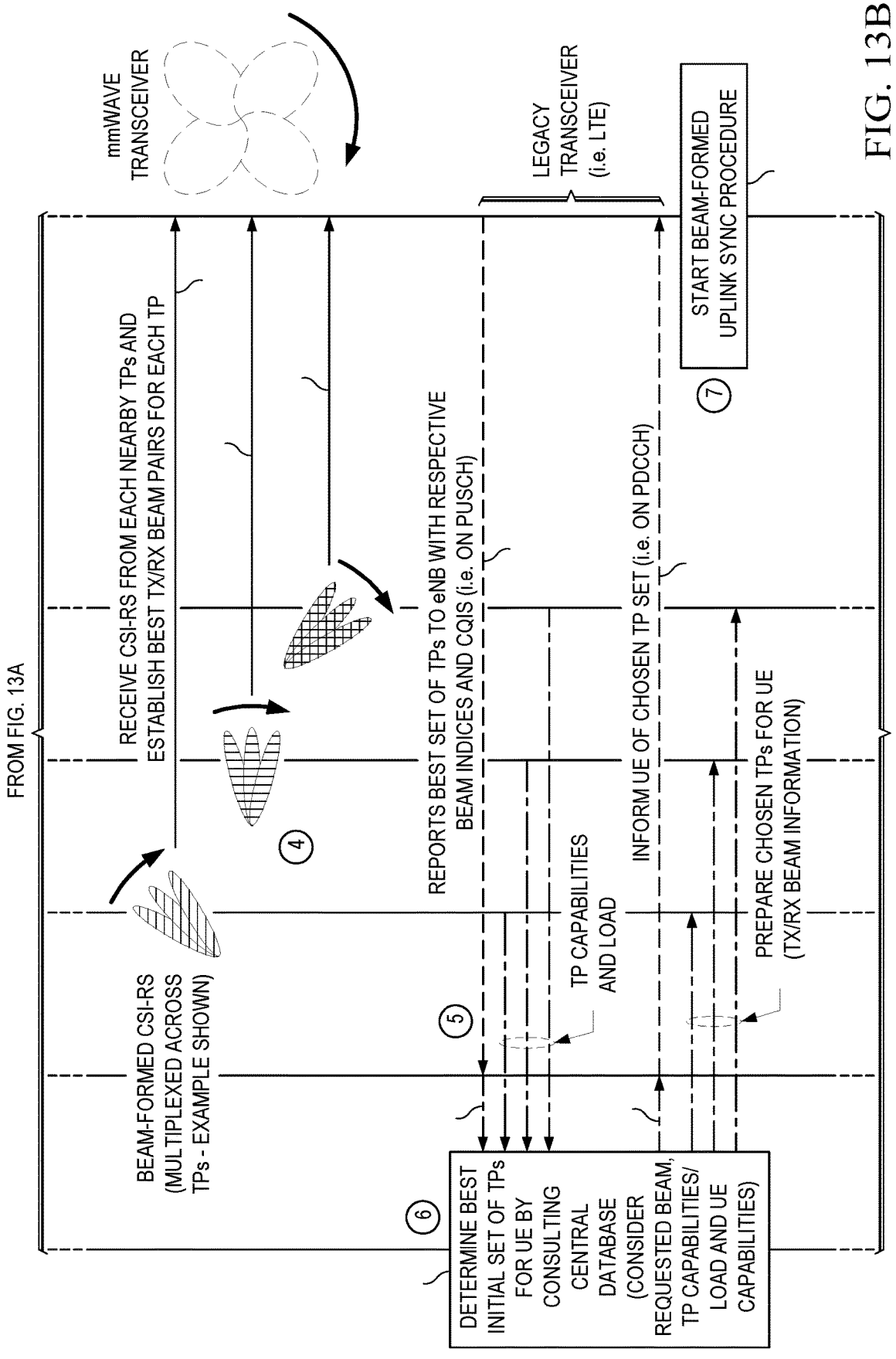

mmWAVE TRANSCEIVER
LEGACY TRANSCEIVER (i.e. LTE)
FROM FIG. 13A
TO FIG. 13C
BEAM-FORMED CSI-RS (MULTIPLEXED ACROSS TPs - EXAMPLE SHOWN)
RECEIVE CSI-RS FROM EACH NEARBY TPs AND ESTABLISH BEST TX/RX BEAM PAIRS FOR EACH TP
REPORTS BEST SET OF TPs TO eNB WITH RESPECTIVE BEAM INDICES AND CQIS (i.e. ON PUSCH)
TP CAPABILITIES AND LOAD
INFORM UE OF CHOSEN TP SET (i.e. ON PDCCH)
PREPARE CHOSEN TPs FOR UE (TX/RX BEAM INFORMATION)
START BEAM-FORMED UPLINK SYNC PROCEDURE
DETERMINE BEST INITIAL SET OF TPs FOR UE BY CONSULTING CENTRAL DATABASE (CONSIDER REQUESTED BEAM, TP CAPABILITIES/ LOAD AND UE CAPABILITIES)
4
5
6
7

FIG. 13B

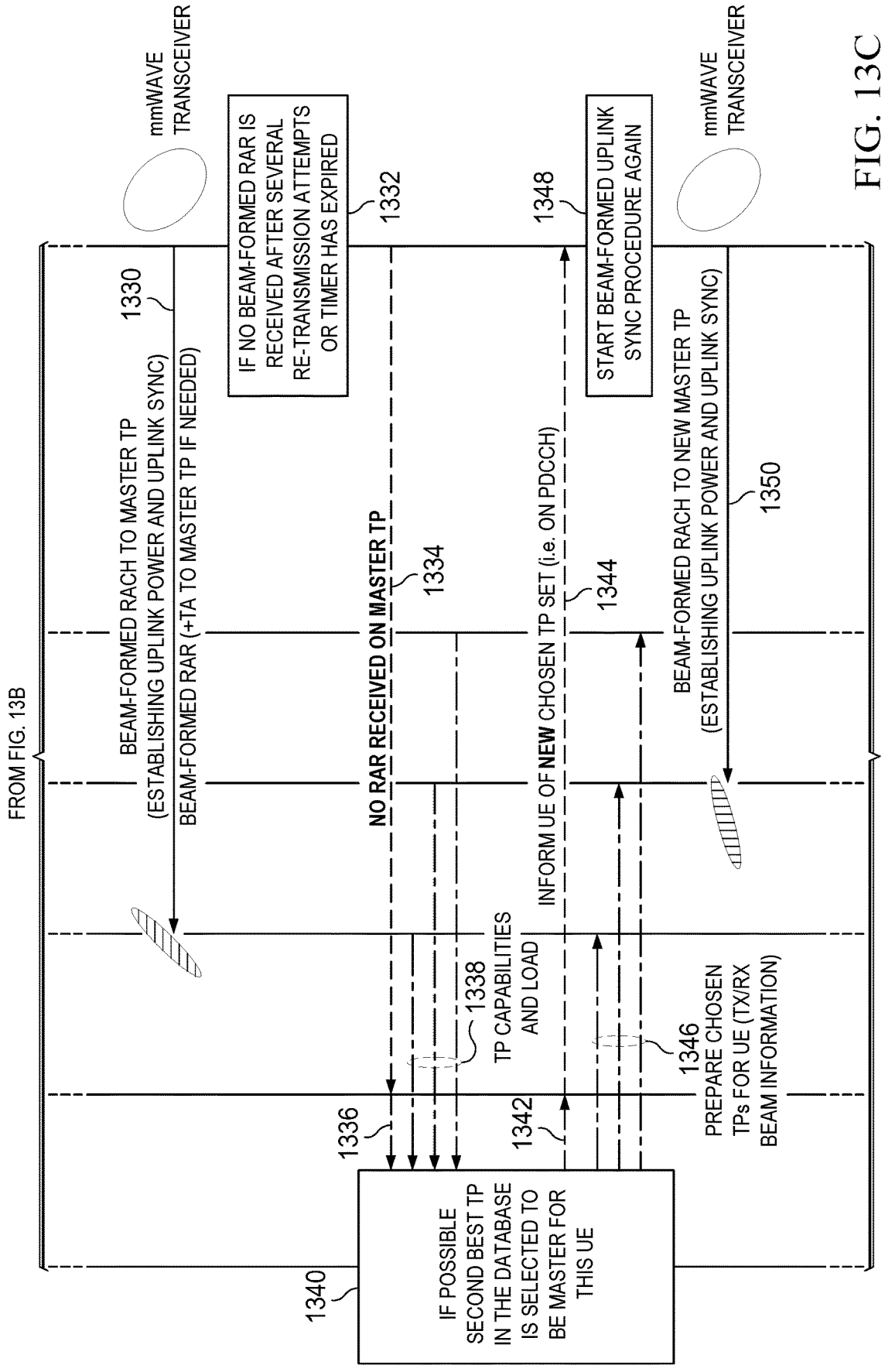

mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
FROM FIG. 13B
TO FIG. 13D
1330
BEAM-FORMED RACH TO MASTER TP (ESTABLISHING UPLINK POWER AND UPLINK SYNC)
BEAM-FORMED RAR (+TA TO MASTER TP IF NEEDED)
IF NO BEAM-FORMED RAR IS RECEIVED AFTER SEVERAL RE-TRANSMISSION ATTEMPTS OR TIMER HAS EXPIRED
1332
NO RAR RECEIVED ON MASTER TP
1334
1348
START BEAM-FORMED UPLINK SYNC PROCEDURE AGAIN
INFORM UE OF NEW CHOSEN TP SET (i.e. ON PDCCH)
1344
BEAM-FORMED RACH TO NEW MASTER TP (ESTABLISHING UPLINK POWER AND UPLINK SYNC)
1350
1338
TP CAPABILITIES AND LOAD
1346
PREPARE CHOSEN TPs FOR UE (TX/RX BEAM INFORMATION)
1336
1342
1340
IF POSSIBLE SECOND BEST TP IN THE DATABASE IS SELECTED TO BE MASTER FOR THIS UE

FIG. 13C

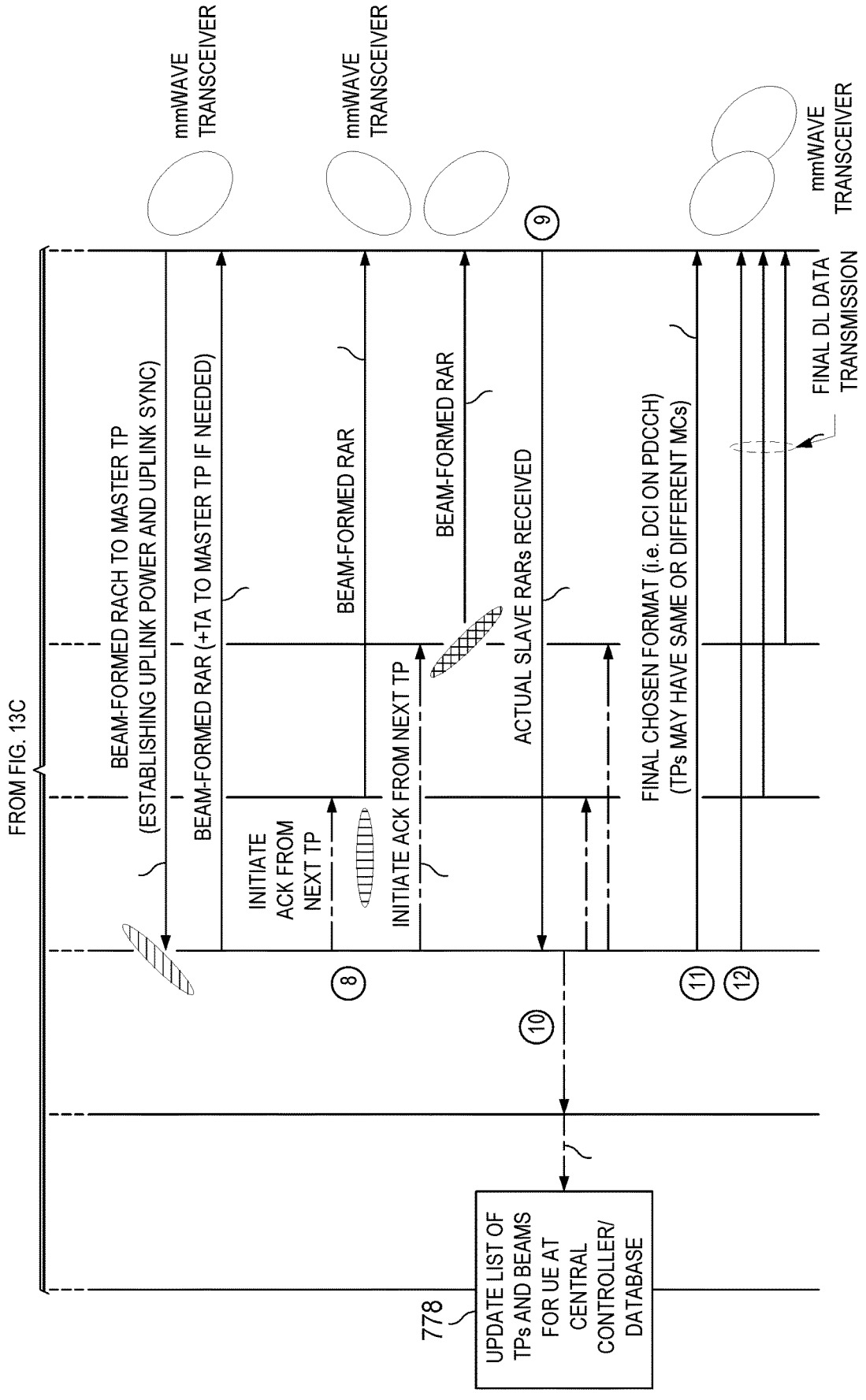

FROM FIG. 13C
mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
BEAM-FORMED RACH TO MASTER TP (ESTABLISHING UPLINK POWER AND UPLINK SYNC)
BEAM-FORMED RAR (+TA TO MASTER TP IF NEEDED)
BEAM-FORMED RAR
BEAM-FORMED RAR
INITIATE ACK FROM NEXT TP
INITIATE ACK FROM NEXT TP
ACTUAL SLAVE RARs RECEIVED
FINAL CHOSEN FORMAT (i.e. DCI ON PDCCH) (TPs MAY HAVE SAME OR DIFFERENT MCs)
FINAL DL DATA TRANSMISSION
8
9
10
11
12
778
UPDATE LIST OF TPs AND BEAMS FOR UE AT CENTRAL CONTROLLER/ DATABASE

FIG. 13D

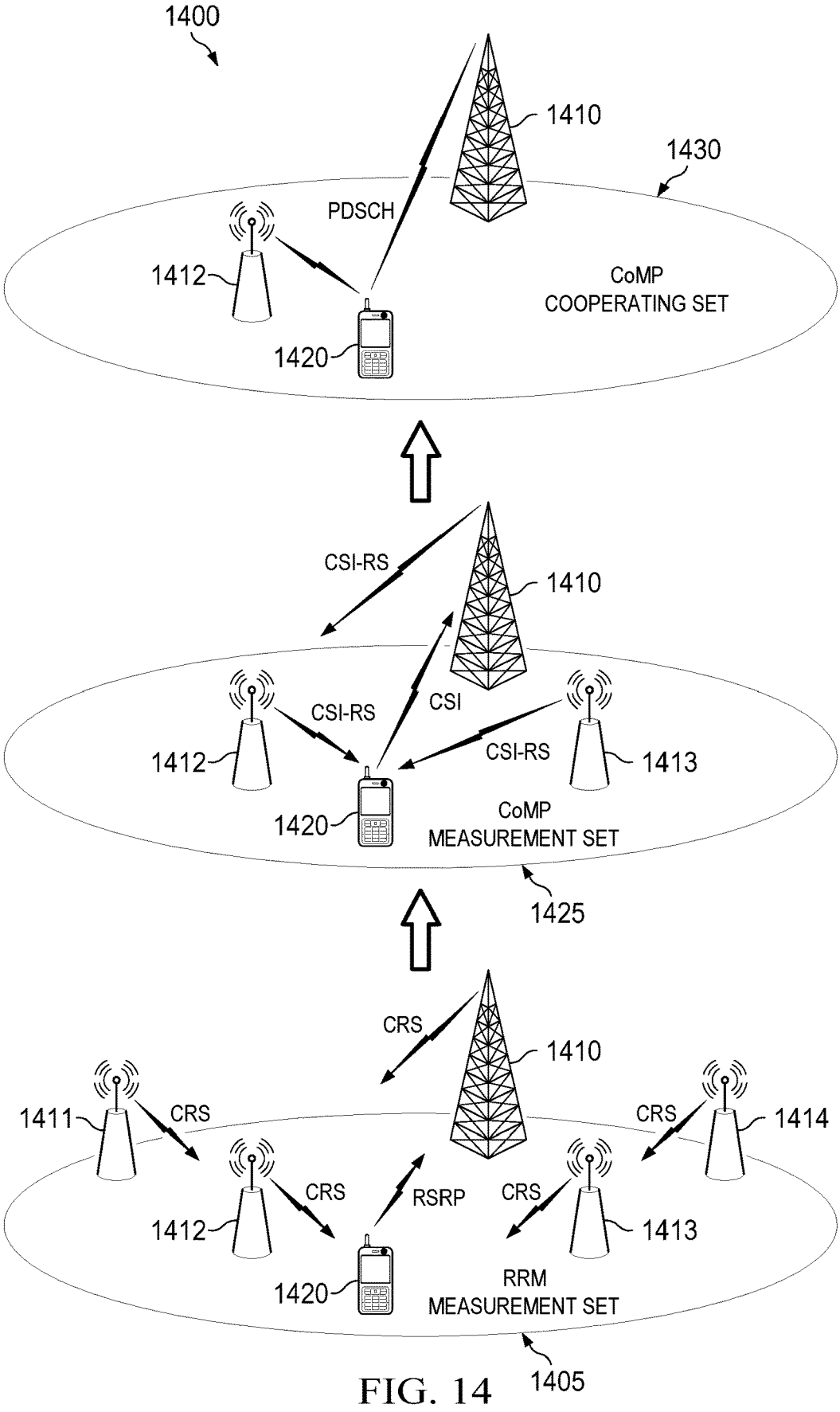

1400
1410
1430
PDSCH
1412
CoMP
COOPERATING SET
1420
CSI-RS
1410
CSI-RS
CSI
CSI-RS
1412
1413
1420
CoMP
MEASUREMENT SET
1425
CRS
1410
1411
CRS
CRS
1414
CRS
RSRP
CRS
1412
1413
1420
RRM
MEASUREMENT SET
1405

FIG. 14

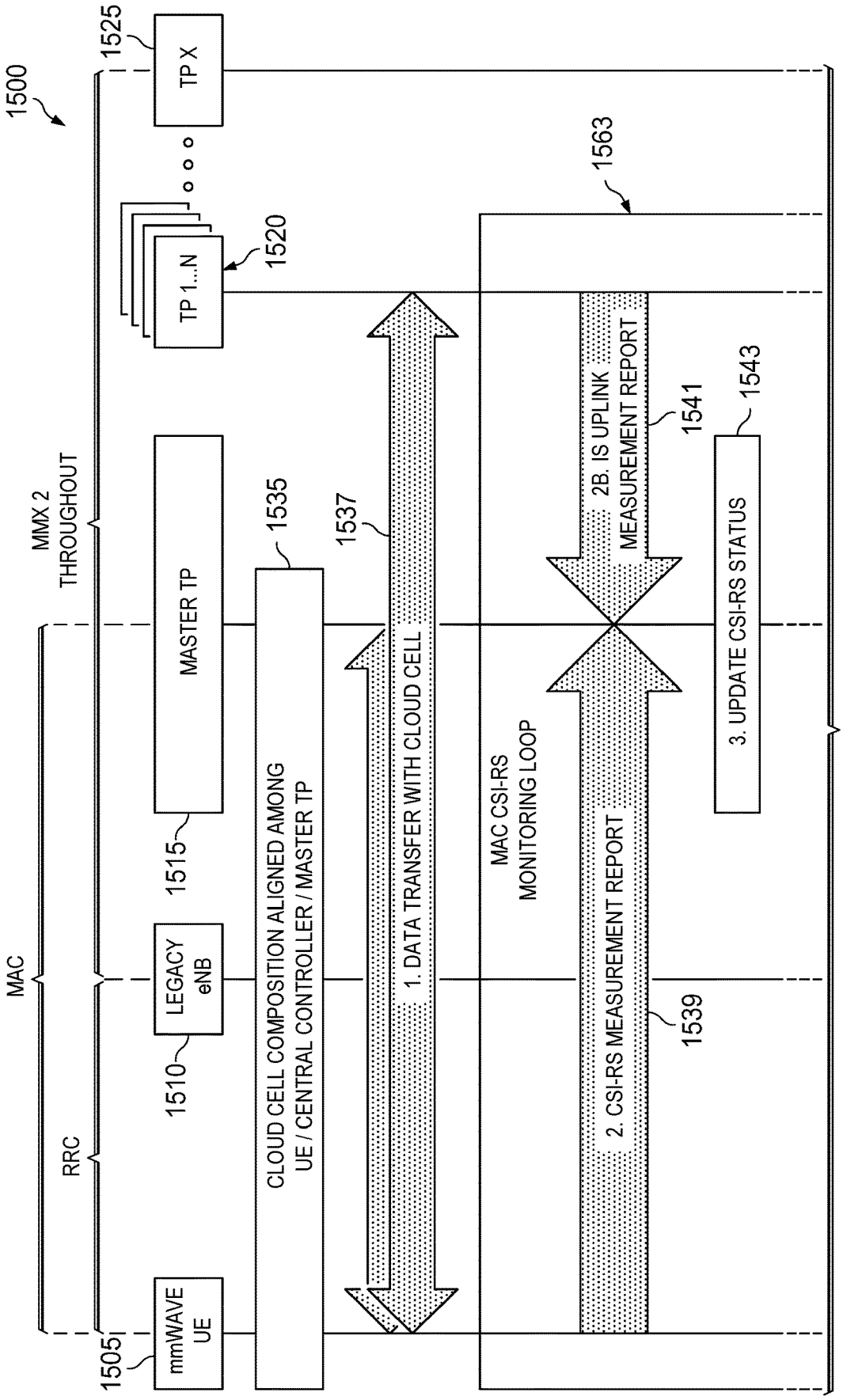

1500
1525
TP X
1520
TP 1...N
1563
MMX 2
THROUGHOUT
MASTER TP
1535
1537
1541
1543
2B. IS UPLINK
MEASUREMENT REPORT
3. UPDATE CSI-RS STATUS
MAC
1515
LEGACY
eNB
1510
RRC
CLOUD CELL COMPOSITION ALIGNED AMONG
UE / CENTRAL CONTROLLER / MASTER TP
1. DATA TRANSFER WITH CLOUD CELL
MAC CSI-RS
MONITORING LOOP
2. CSI-RS MEASUREMENT REPORT
1539
TO FIG. 15B
1505
mmWAVE
UE

FIG. 15A

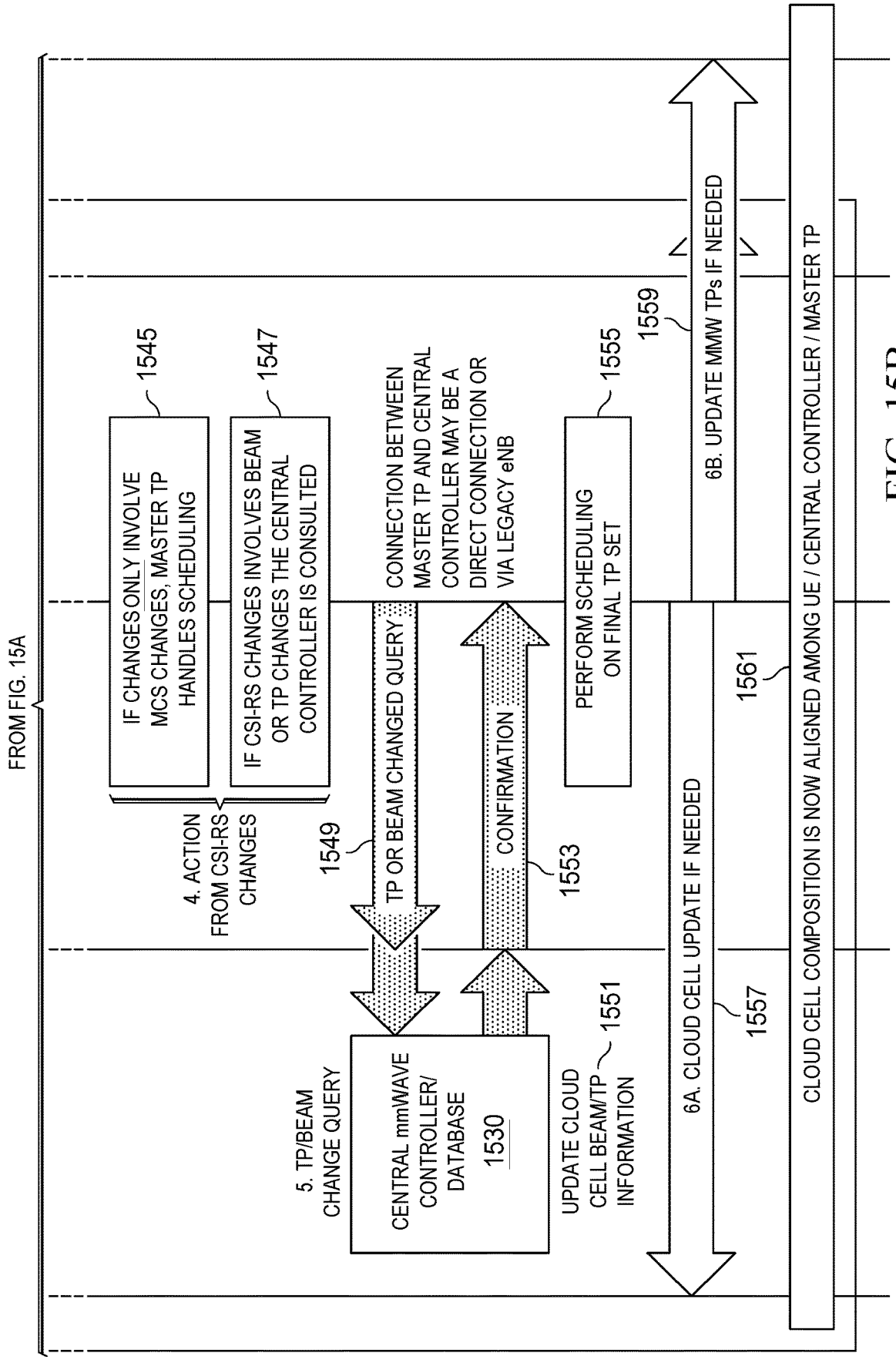

FROM FIG. 15A
IF CHANGES ONLY INVOLVE MCS CHANGES, MASTER TP HANDLES SCHEDULING
1545
IF CSI-RS CHANGES INVOLVES BEAM OR TP CHANGES THE CENTRAL CONTROLLER IS CONSULTED
1547
4. ACTION FROM CSI-RS CHANGES
1549
TP OR BEAM CHANGED QUERY
CONFIRMATION
1553
CONNECTION BETWEEN MASTER TP AND CENTRAL CONTROLLER MAY BE A DIRECT CONNECTION OR VIA LEGACY eNB
PERFORM SCHEDULING ON FINAL TP SET
1555
1559
6B. UPDATE MMW TPs IF NEEDED
5. TP/BEAM CHANGE QUERY
CENTRAL mmWAVE CONTROLLER/ DATABASE 1530
UPDATE CLOUD CELL BEAM/TP INFORMATION
1551
6A. CLOUD CELL UPDATE IF NEEDED
1557
1561
CLOUD CELL COMPOSITION IS NOW ALIGNED AMONG UE / CENTRAL CONTROLLER / MASTER TP

FIG. 15B

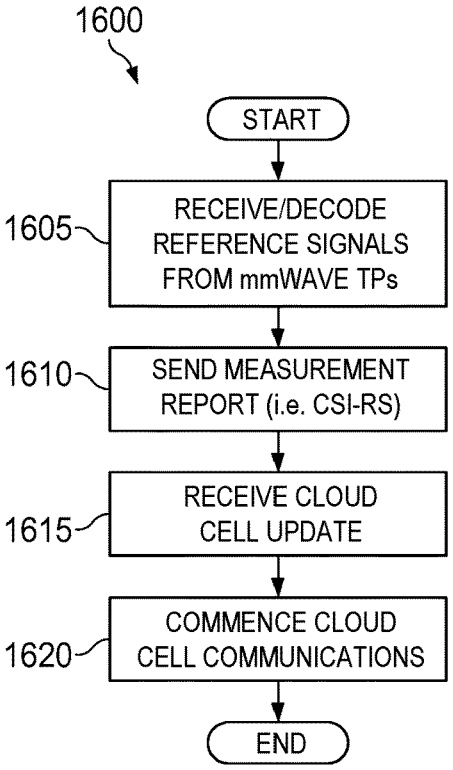

1600
START
1605
RECEIVE/DECODE REFERENCE SIGNALS FROM mmWAVE TPs
1610
SEND MEASUREMENT REPORT (i.e. CSI-RS)
1615
RECEIVE CLOUD CELL UPDATE
1620
COMMENCE CLOUD CELL COMMUNICATIONS
END

FIG. 16

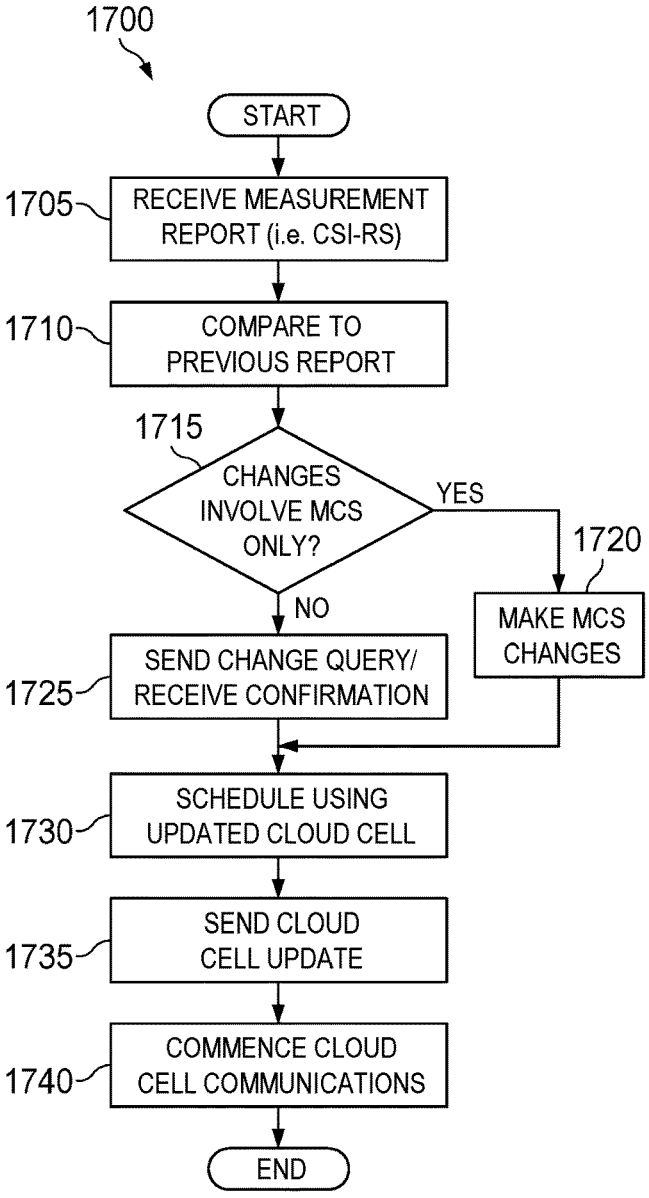

1700
START
1705
RECEIVE MEASUREMENT REPORT (i.e. CSI-RS)
1710
COMPARE TO PREVIOUS REPORT
1715
CHANGES INVOLVE MCS ONLY?
YES
1720
MAKE MCS CHANGES
NO
1725
SEND CHANGE QUERY/ RECEIVE CONFIRMATION
1730
SCHEDULE USING UPDATED CLOUD CELL
1735
SEND CLOUD CELL UPDATE
1740
COMMENCE CLOUD CELL COMMUNICATIONS
END

FIG. 17

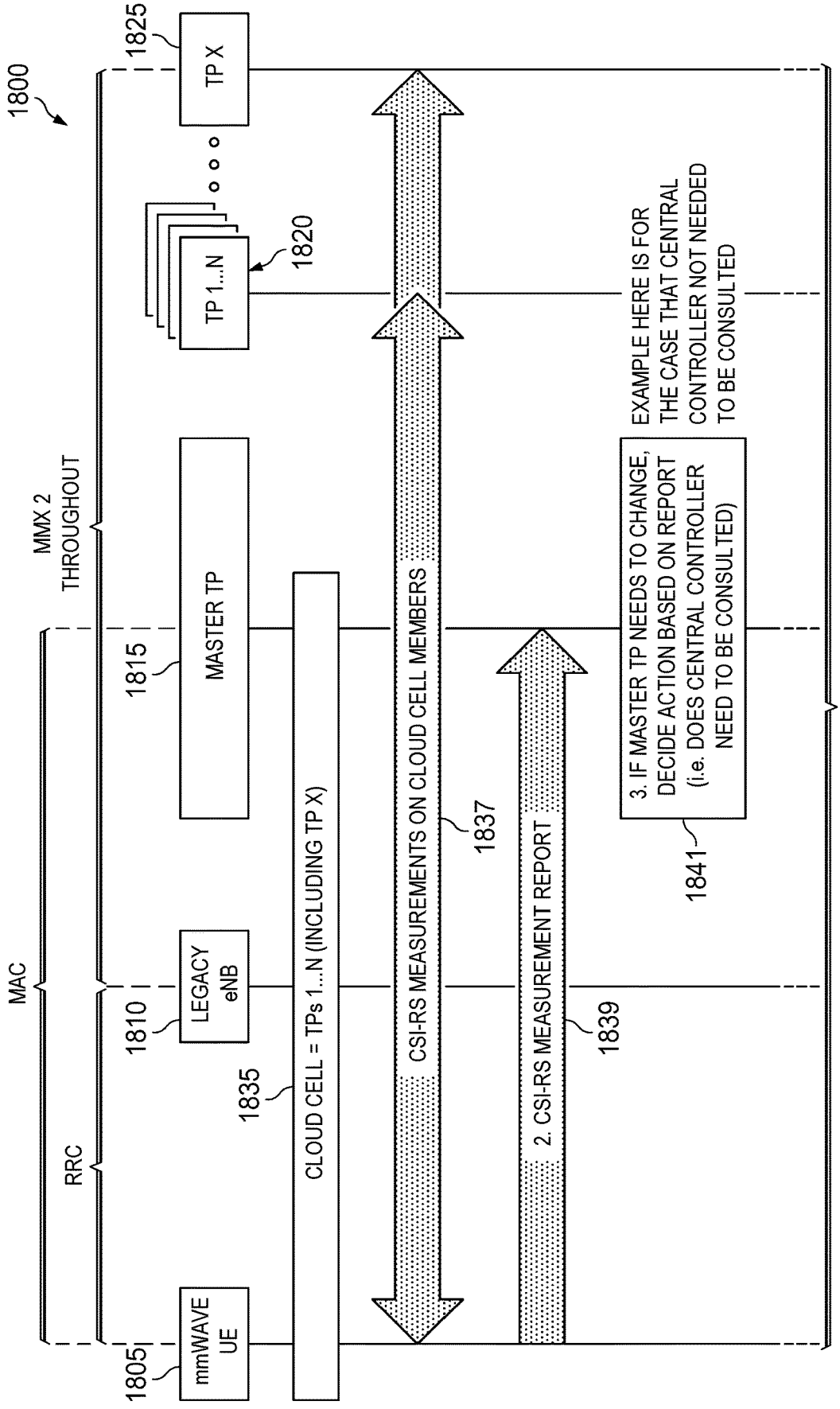

1800
1825
TP X
TP 1...N
1820
MMX 2
THROUGHOUT
1815
MASTER TP
CLOUD CELL = TPs 1...N (INCLUDING TP X)
1835
CSI-RS MEASUREMENTS ON CLOUD CELL MEMBERS
1837
2. CSI-RS MEASUREMENT REPORT
1839
3. IF MASTER TP NEEDS TO CHANGE, DECIDE ACTION BASED ON REPORT (i.e. DOES CENTRAL CONTROLLER NEED TO BE CONSULTED)
1841
EXAMPLE HERE IS FOR THE CASE THAT CENTRAL CONTROLLER NOT NEEDED TO BE CONSULTED
TO FIG. 18B
MAC
RRC
1810
LEGACY eNB
1805
mmWAVE UE

FIG. 18A

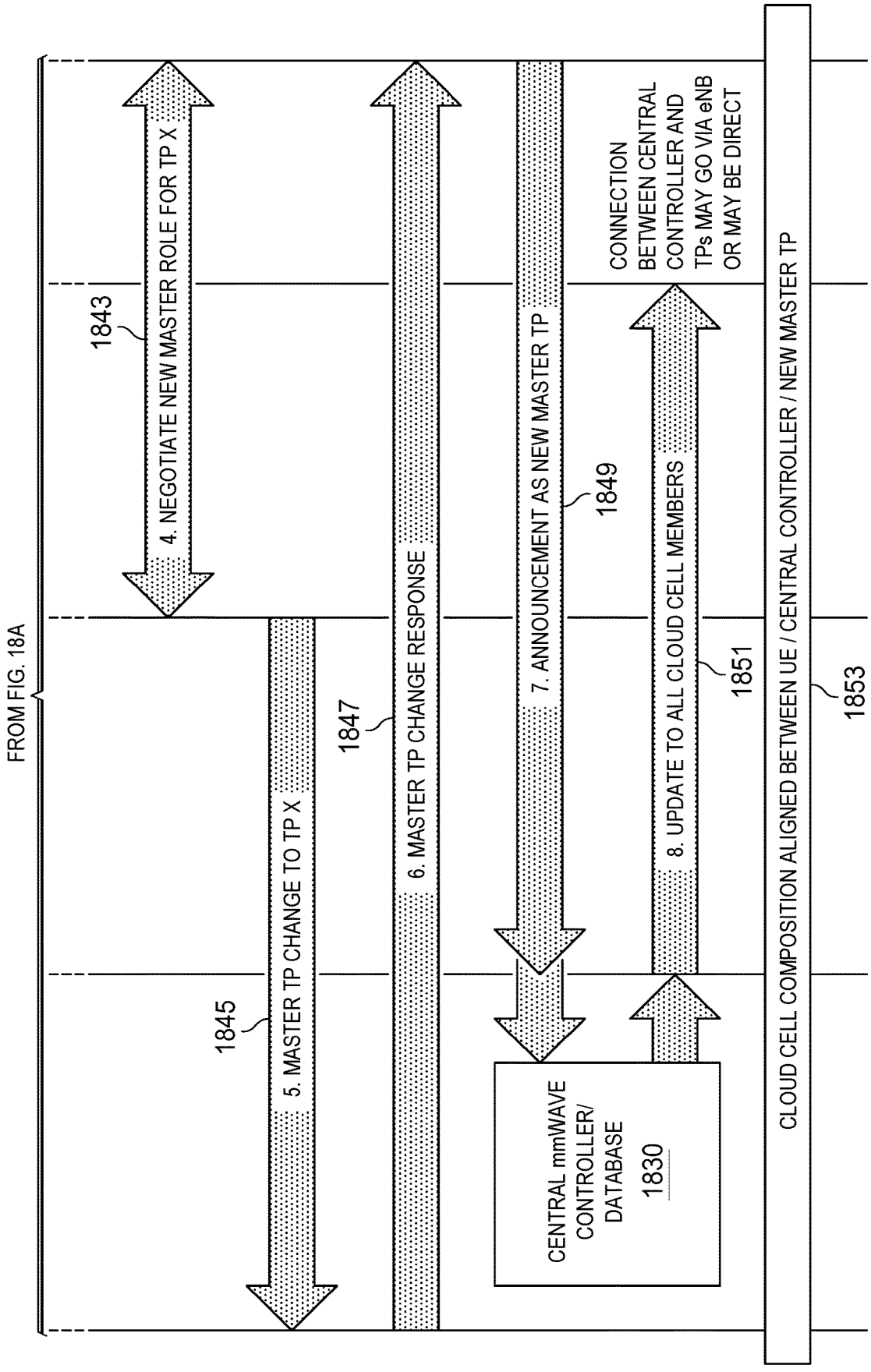

FROM FIG. 18A
1843
4. NEGOTIATE NEW MASTER ROLE FOR TP X
1845
5. MASTER TP CHANGE TO TP X
1847
6. MASTER TP CHANGE RESPONSE
7. ANNOUNCEMENT AS NEW MASTER TP
1849
8. UPDATE TO ALL CLOUD CELL MEMBERS
1851
CONNECTION BETWEEN CENTRAL CONTROLLER AND TPs MAY GO VIA eNB OR MAY BE DIRECT
CENTRAL mmWAVE CONTROLLER/ DATABASE 1830
CLOUD CELL COMPOSITION ALIGNED BETWEEN UE / CENTRAL CONTROLLER / NEW MASTER TP
1853

FIG. 18B

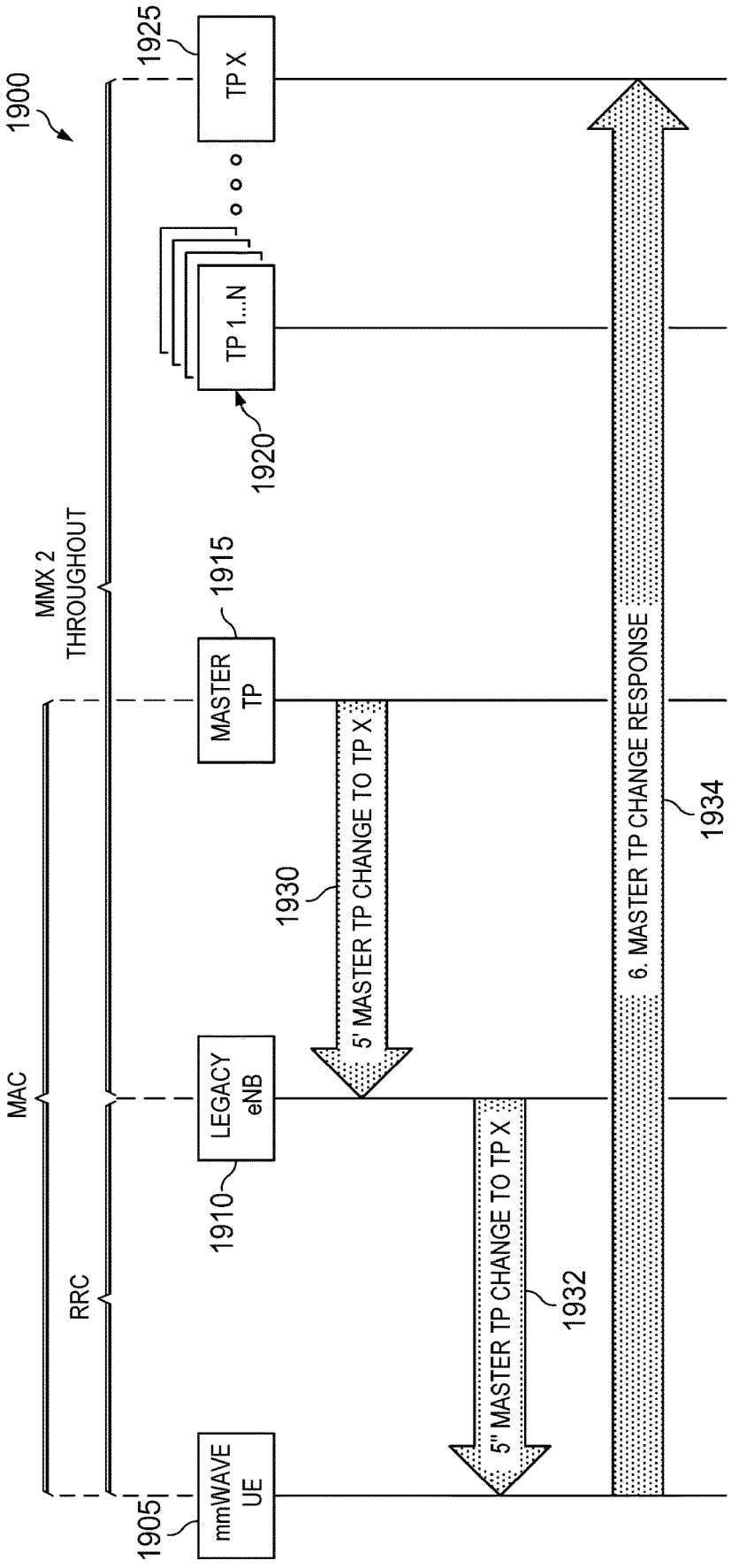

1900
1925
TP X
TP 1...N
1920
MMX 2 THROUGHOUT
1915
MASTER TP
1930
5' MASTER TP CHANGE TO TP X
6. MASTER TP CHANGE RESPONSE
1934
MAC
LEGACY eNB
1910
RRC
5'' MASTER TP CHANGE TO TP X
1932
mmWAVE UE
1905

FIG. 19

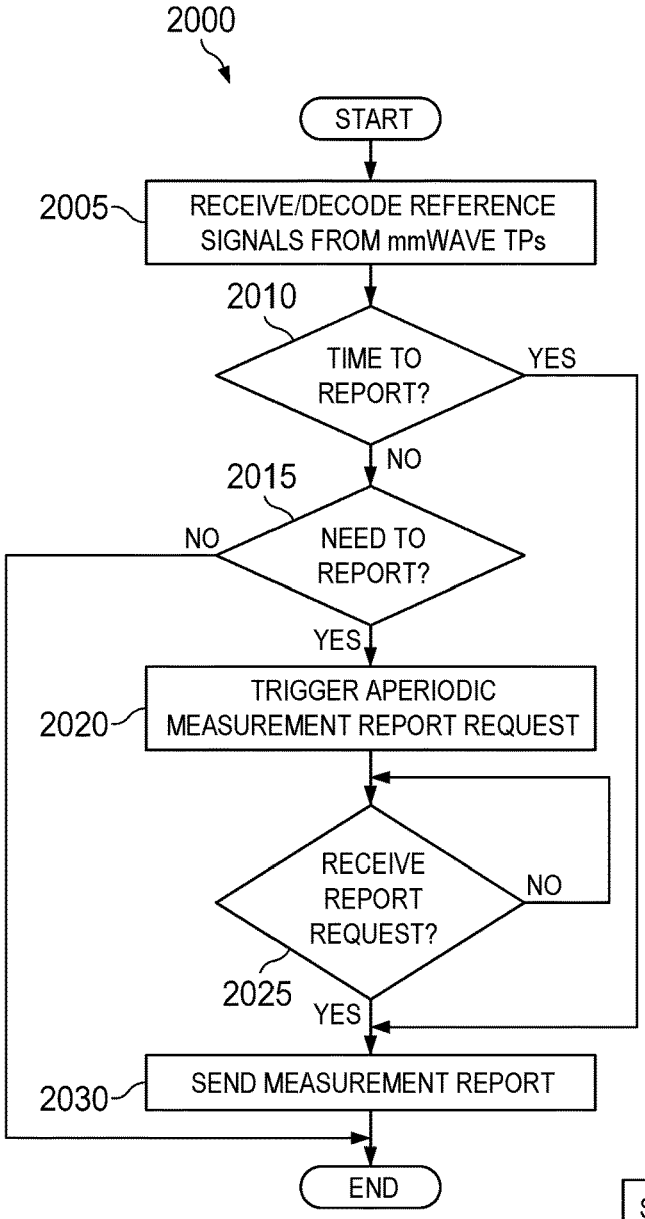


FIG. 20A

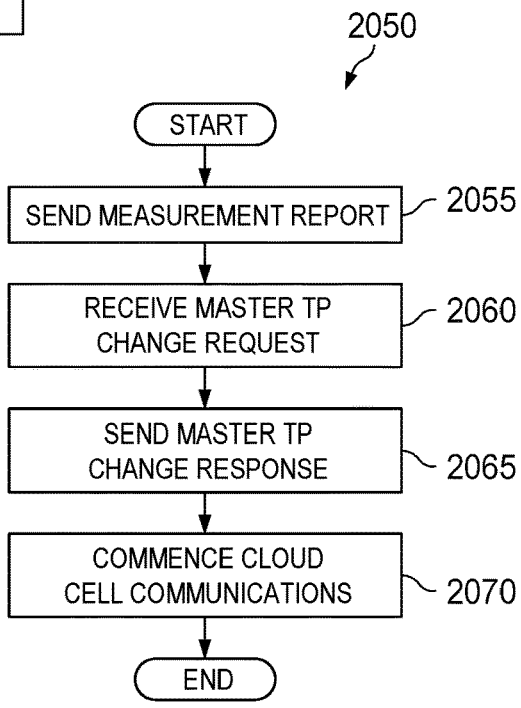


FIG. 20B

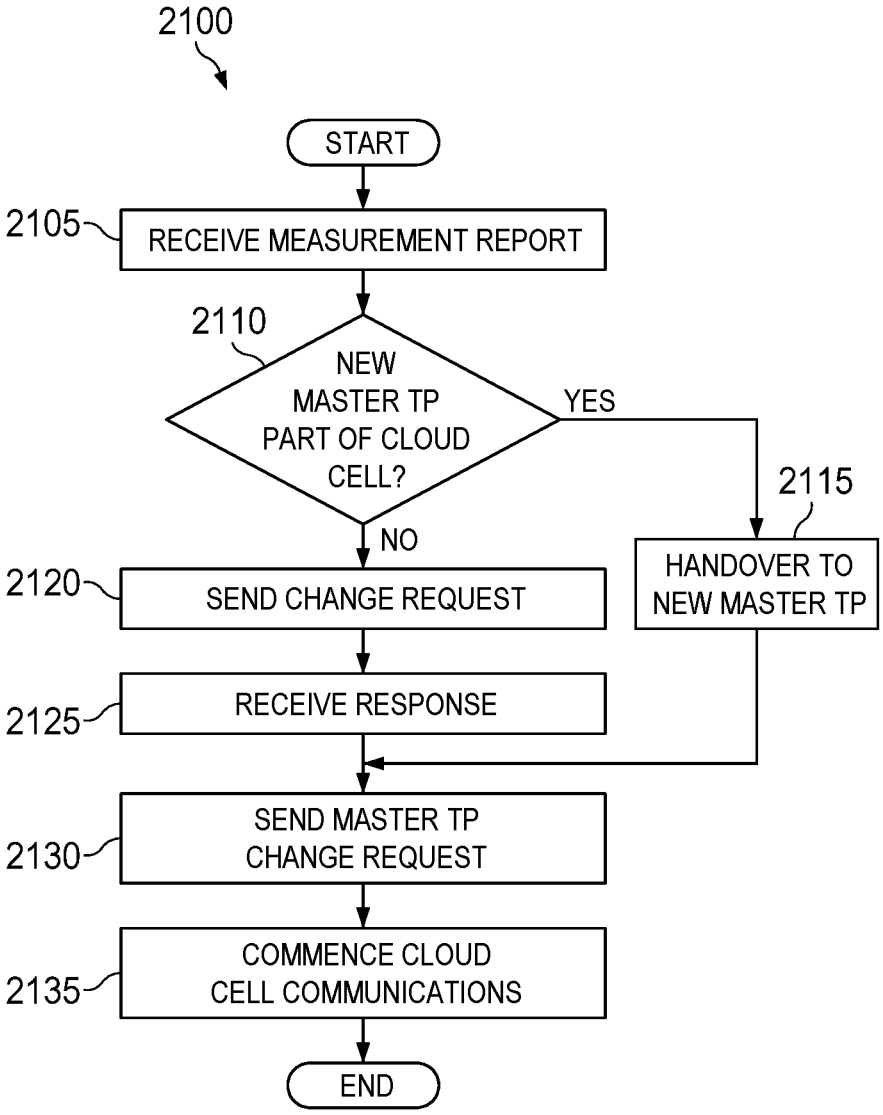

2100
START
2105
RECEIVE MEASUREMENT REPORT
2110
NEW MASTER TP PART OF CLOUD CELL?
YES
NO
2115
HANDOVER TO NEW MASTER TP
2120
SEND CHANGE REQUEST
2125
RECEIVE RESPONSE
2130
SEND MASTER TP CHANGE REQUEST
2135
COMMENCE CLOUD CELL COMMUNICATIONS
END

FIG. 21

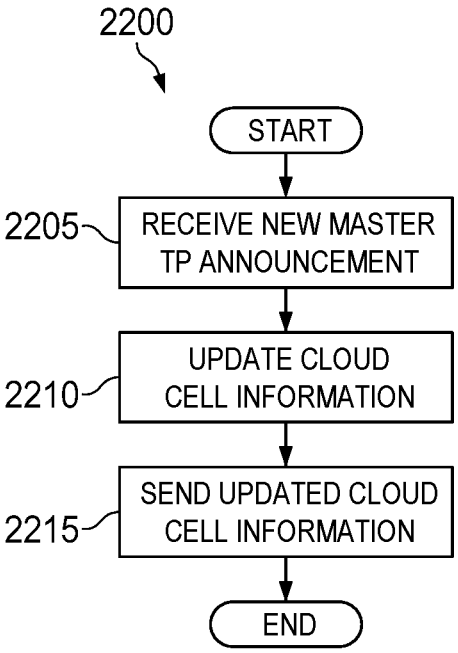

2200
START
2205
RECEIVE NEW MASTER TP ANNOUNCEMENT
2210
UPDATE CLOUD CELL INFORMATION
2215
SEND UPDATED CLOUD CELL INFORMATION
END

FIG. 22

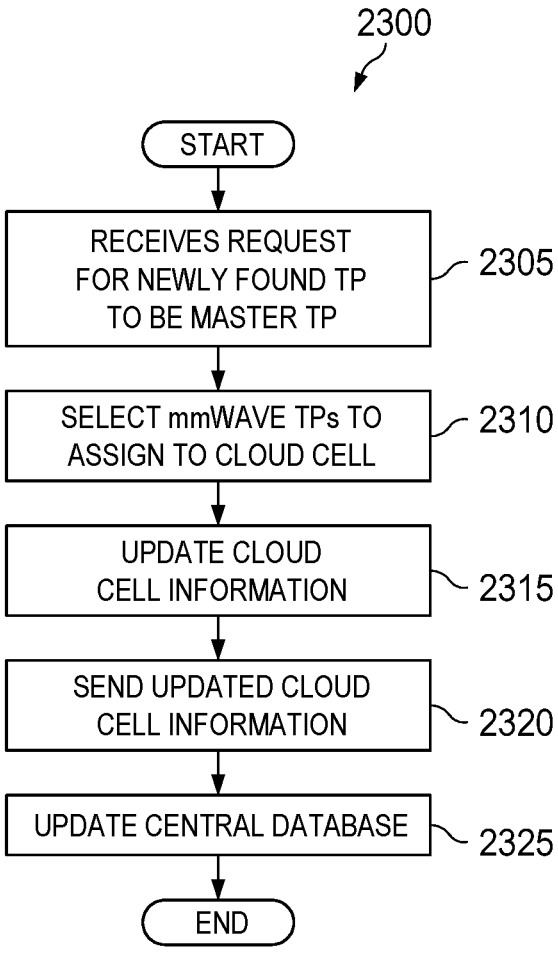

2300
START
RECEIVES REQUEST FOR NEWLY FOUND TP TO BE MASTER TP
2305
SELECT mmWAVE TPs TO ASSIGN TO CLOUD CELL
2310
UPDATE CLOUD CELL INFORMATION
2315
SEND UPDATED CLOUD CELL INFORMATION
2320
UPDATE CENTRAL DATABASE
2325
END

FIG. 23

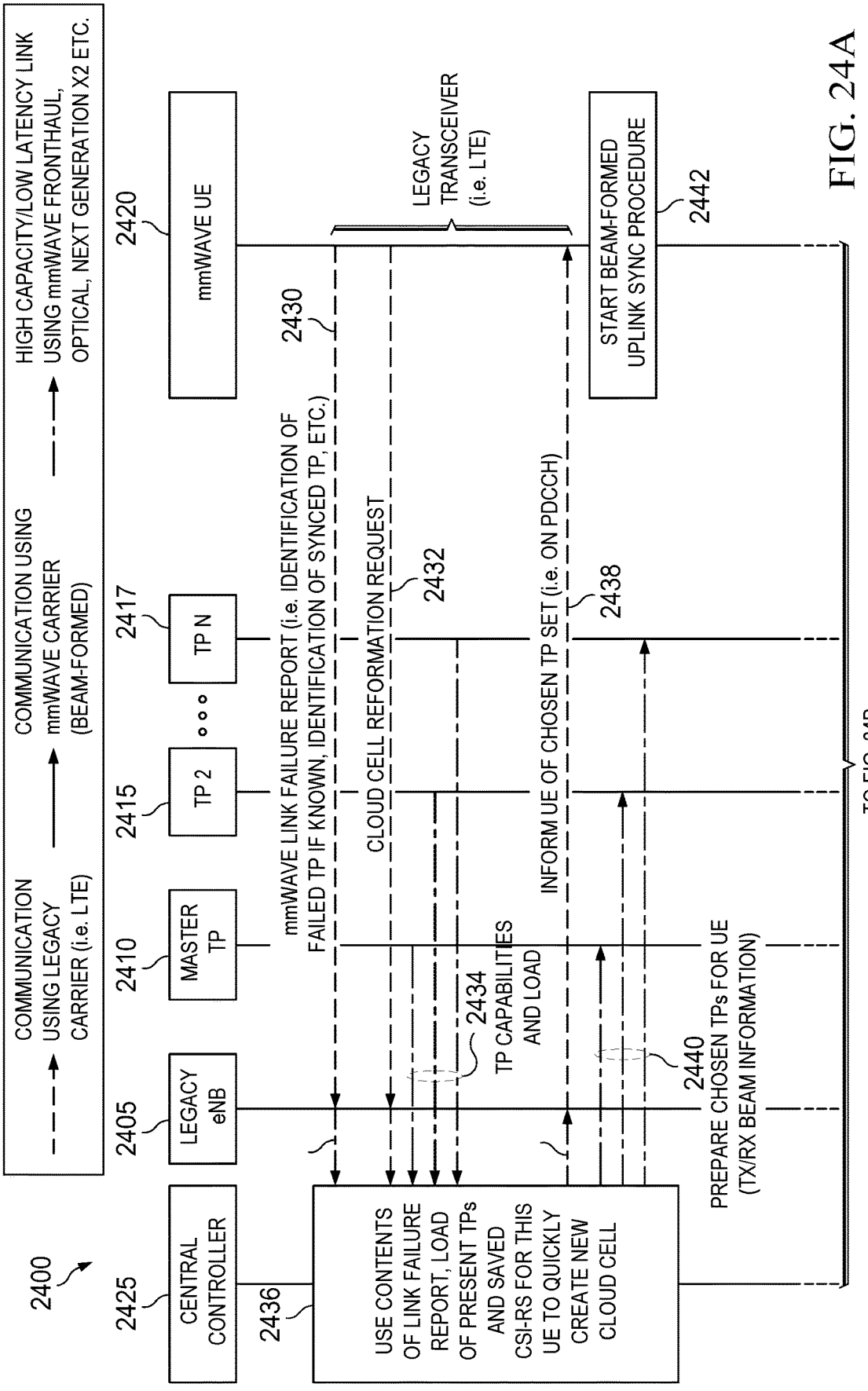

2400
2425
CENTRAL CONTROLLER
2436
2405
LEGACY eNB
2410
MASTER TP
2415
TP 2
2417
TP N
2420
mmWAVE UE
COMMUNICATION USING LEGACY CARRIER (i.e. LTE)
COMMUNICATION USING mmWAVE CARRIER (BEAM-FORMED)
HIGH CAPACITY/LOW LATENCY LINK USING mmWAVE FRONTHAUL, OPTICAL, NEXT GENERATION X2 ETC.
LEGACY TRANSCEIVER (i.e. LTE)
mmWAVE LINK FAILURE REPORT (i.e. IDENTIFICATION OF FAILED TP IF KNOWN, IDENTIFICATION OF SYNCED TP, ETC.)
2430
CLOUD CELL REFORMATION REQUEST
2432
2434
TP CAPABILITIES AND LOAD
INFORM UE OF CHOSEN TP SET (i.e. ON PDCCH)
2438
2440
PREPARE CHOSEN TPs FOR UE (TX/RX BEAM INFORMATION)
START BEAM-FORMED UPLINK SYNC PROCEDURE
2442
USE CONTENTS OF LINK FAILURE REPORT, LOAD OF PRESENT TPs AND SAVED CSI-RS FOR THIS UE TO QUICKLY CREATE NEW CLOUD CELL
TO FIG. 24B

FIG. 24A

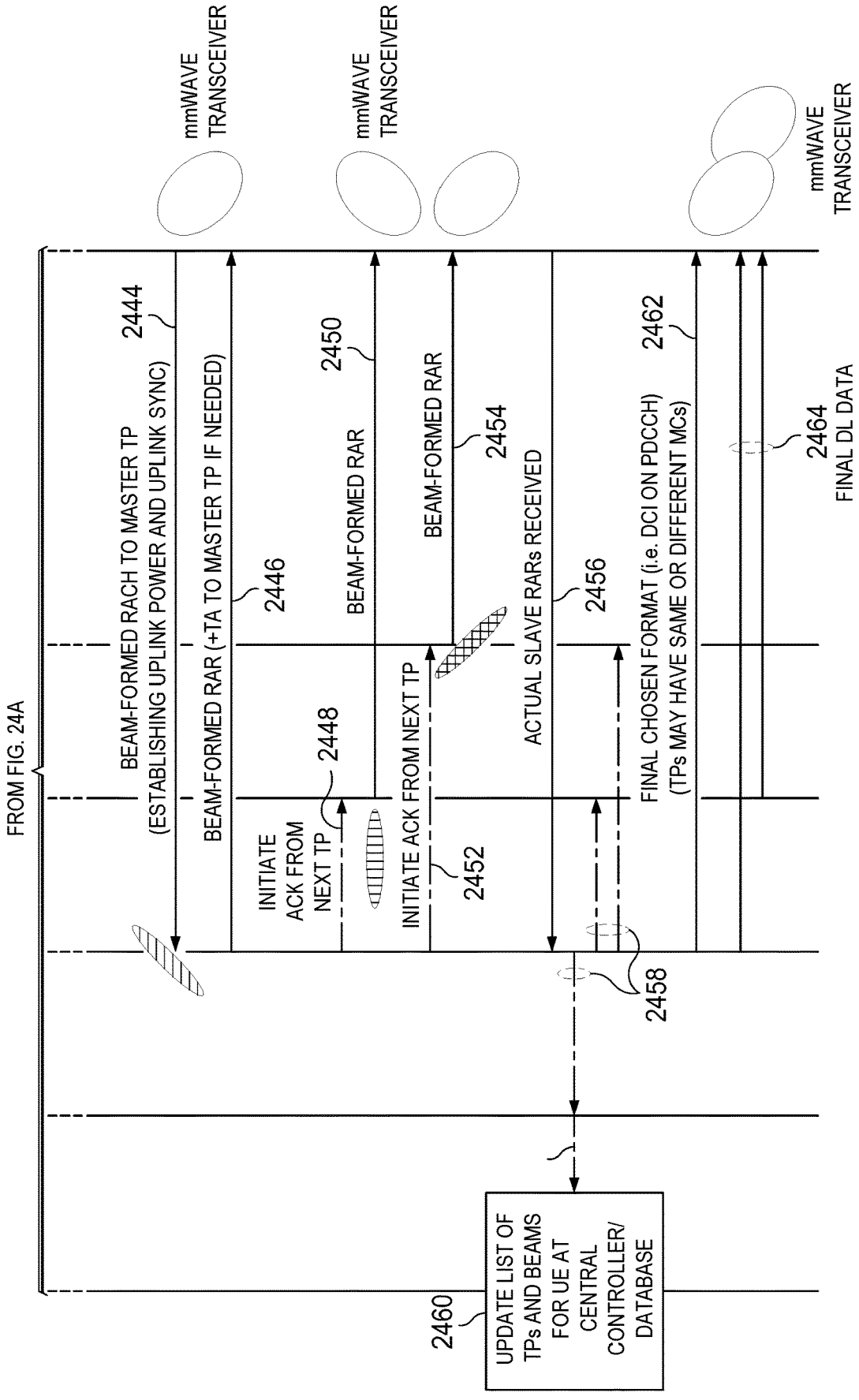

mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
mmWAVE TRANSCEIVER
FROM FIG. 24A
BEAM-FORMED RACH TO MASTER TP (ESTABLISHING UPLINK POWER AND UPLINK SYNC)
2444
BEAM-FORMED RAR (+TA TO MASTER TP IF NEEDED)
2446
INITIATE ACK FROM NEXT TP
2448
BEAM-FORMED RAR
2450
INITIATE ACK FROM NEXT TP
2452
BEAM-FORMED RAR
2454
ACTUAL SLAVE RARs RECEIVED
2456
FINAL CHOSEN FORMAT (i.e. DCI ON PDCCH) (TPs MAY HAVE SAME OR DIFFERENT MCs)
2462
2458
2464
FINAL DL DATA TRANSMISSION
2460
UPDATE LIST OF TPs AND BEAMS FOR UE AT CENTRAL CONTROLLER/ DATABASE

FIG. 24B

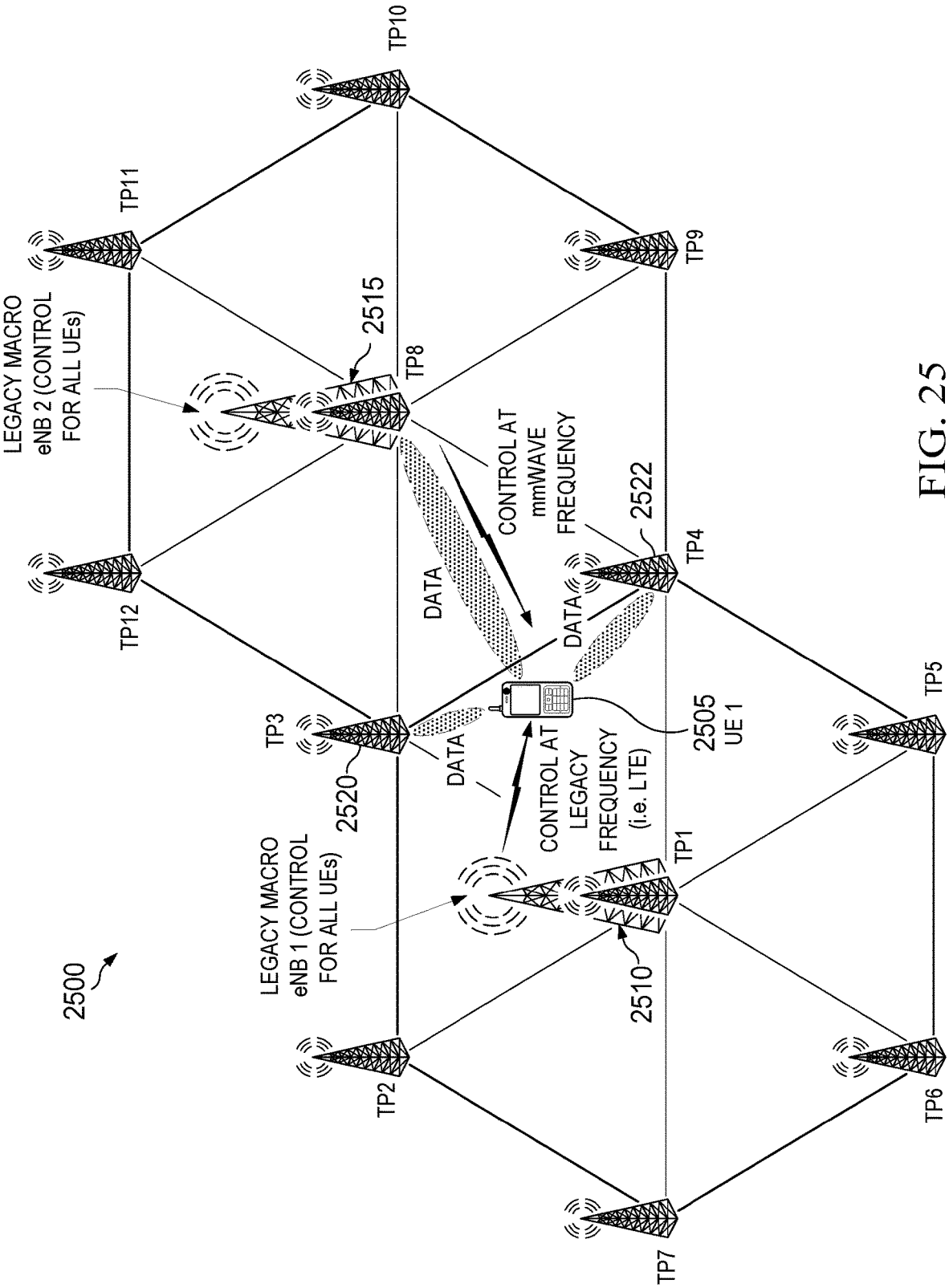

2500
TP10
TP11
TP9
LEGACY MACRO eNB 2 (CONTROL FOR ALL UEs)
2515
TP8
CONTROL AT mmWAVE FREQUENCY
2522
TP4
TP12
DATA
DATA
TP3
TP5
2505 UE 1
2520
DATA
CONTROL AT LEGACY FREQUENCY (i.e. LTE)
LEGACY MACRO eNB 1 (CONTROL FOR ALL UEs)
TP1
2510
TP2
TP6
TP7

FIG. 25

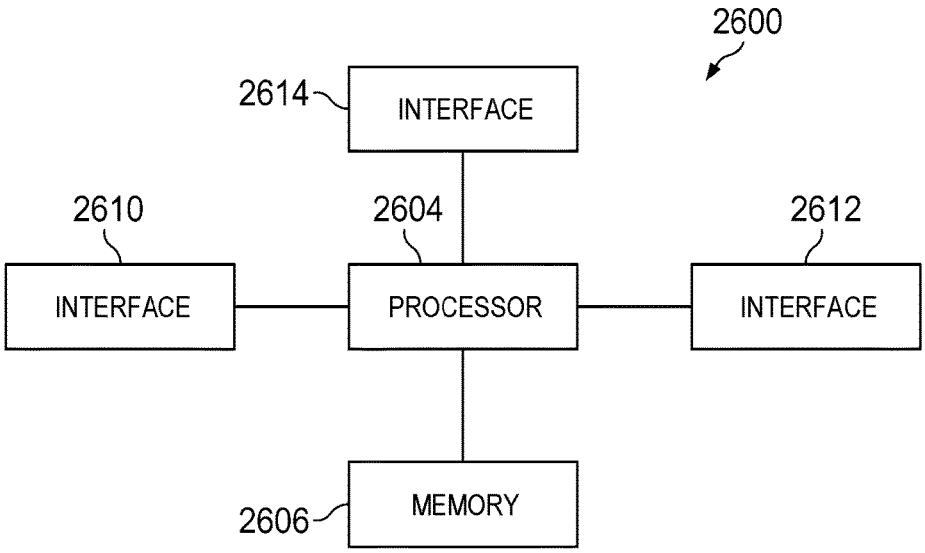

2600
2614
INTERFACE
2610
2604
2612
INTERFACE
PROCESSOR
INTERFACE
2606
MEMORY

FIG. 26

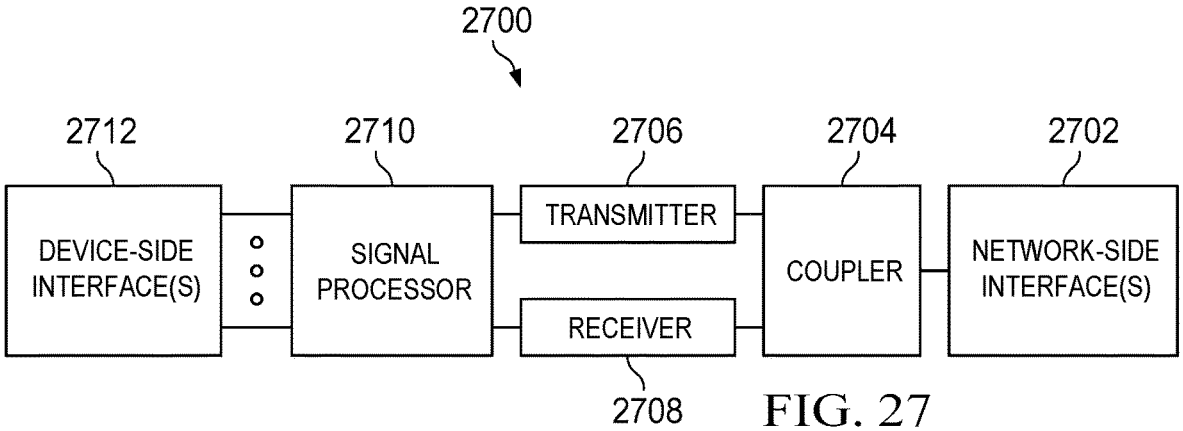

2700
2712
2710
2706
2704
2702
DEVICE-SIDE INTERFACE(S)
SIGNAL PROCESSOR
TRANSMITTER
RECEIVER
COUPLER
NETWORK-SIDE INTERFACE(S)
2708

FIG. 27

SYSTEM AND METHOD FOR MILLIMETER WAVE COMMUNICATIONS

This application is a continuation of U.S. application Ser. No. 15/092,388, filed on Apr. 6, 2016, entitled "System and Method for Millimeter Wave Communications," which application is hereby incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates generally to digital communications, and more particularly to a system and method for millimeter wave (mmWave) communications.

BACKGROUND

Some wireless communications systems, especially those operating in high frequencies (e.g., 6 GHz and above), often have communications links that are readily blocked by stationary or moving objects. Communications links with such characteristics are often referred to as being fragile or having link fragility.

SUMMARY OF THE DISCLOSURE

Example embodiments provide a system and method for millimeter wave (mmWave) communications

In accordance with an example embodiment, a method for operating a millimeter wave (mmWave) user equipment (UE) is provided. The method includes measuring, by the mmWave UE, beam-formed reference signals transmitted by a plurality of mmWave transmission points (TPs), sending, by the mmWave UE, a cloud cell formation request including a measurement report comprising indicators associated with best mmWave TPs determined in accordance with the measured beam-formed reference signals, receiving, by the mmWave UE, a cloud cell formation request response including indicators associated with a subset of the best mmWave TPs selected by a central controller in accordance with selection information, where the subset of the best mmWave TPs includes a first mmWave transmission point (TP) serving as a master TP and a second mmWave TP serving as a slave TP, and establishing, by the mmWave UE, a cloud cell with mmWave TPs of the subset of the best mmWave TPs selected by the central controller, where a data connection is established with the slave TP and at least a control connection is established with the master TP.

In accordance with another example embodiment, a method for operating a central controller is provided. The method includes receiving, by the central controller, a cloud cell formation request including a measurement report comprising best beam-formed reference signals for best mmWave TPs determined in accordance with measured beam-formed reference signals transmitted by the mmWave TPs and indicators associated with the best mmWave TPs, selecting, by the central controller, a subset of the best mmWave TPs in accordance with the best beam-formed reference signals, where the subset of the best mmWave TPs includes a mmWave TP serving as a master TP and a mmWave TP serving as a slave TP, and sending, by the central controller, a cloud cell formation response including indicators associated with the subset of the best mmWave TPs.

In accordance with an example embodiment, a method for operating a first mmWave TP is provided. The method includes performing, by the first mmWave TP, an uplink synchronization with a mmWave UE, initiating, by the first mmWave TP, acknowledgements from second mmWave TPs to the mmWave UE to trigger beam-formed random access channel responses (RARs) to the mmWave UE, receiving, by the first mmWave TP, an indicator of a number of RARs received by the mmWave UE, and sending, by the first mmWave TP, an indicator of selected transmission parameters to the mmWave UE.

In accordance with an example embodiment, a mmWave UE adapted to perform digital communications is provided. The mmWave UE includes a processor, and a computer readable storage medium storing programming for execution by the processor. The programming including instructions to configure the mmWave UE to measure beam-formed reference signals transmitted by a plurality of mmWave TPs, send a cloud cell formation request including a measurement report comprising indicators associated with best mmWave TPs determined in accordance with the measured beam-formed reference signals, receive a cloud cell formation request response including indicators associated with a subset of the best mmWave TPs selected by a central controller in accordance with selection information, where the subset of the best mmWave TPs includes a first mmWave TP serving as a master TP and a second mmWave TP serving as a slave TP, and establish a cloud cell with mmWave TPs of the subset of the best mmWave TPs selected by the central controller, where a data connection is established with the slave TP and at least a control connection is established with the master TP.

In accordance with an example embodiment, a central controller adapted to perform digital communications is provided. The central controller includes a processor, and a computer readable storage medium storing programming for execution by the processor. The programming including instructions to configure the central controller to receive a cloud cell formation request including a measurement report comprising best beam-formed reference signals for best mmWave TPs determined in accordance with measured beam-formed reference signals transmitted by the mmWave TPs and indicators associated with the best mmWave TPs, select a subset of the best mmWave TPs in accordance with the best beam-formed reference signals, where the subset of the best mmWave TPs includes a mmWave transmission point (TP) serving as a master TP and a mmWave TP serving as a slave TP, and send a cloud cell formation response including indicators associated with the subset of the best mmWave TPs.

In accordance with an example embodiment, a first mmWave TP adapted to perform digital communications is provided. The first mmWave TP includes a processor, and a computer readable storage medium storing programming for execution by the processor. The programming including instructions to configure the first mmWave TP to perform an uplink synchronization with a mmWave UE, initiate acknowledgements from second mmWave TPs to the mmWave UE to trigger beam-formed RARs to the mmWave UE, receive an indicator of a number of RARs received by the mmWave UE, and send an indicator of selected transmission parameters to the mmWave UE.

In accordance with an example embodiment, a method for operating a first mmWave TP is provided. The method includes determining, by the first mmWave TP, that a change is needed to a configuration of a UE centric cloud cell, where the determining is in accordance with measurement reports of beam-formed reference signals transmitted by mmWave TPs of a measurement set, and when the change comprises a change to a modulation coding scheme (MCS) level of a communications link associated with the UE centric cloud

cell, adjusting, by the first mmWave TP, the MCS level of the communications link. The method includes when the change comprises at least one of a change to a communications beam or a mmWave TP change, sending, by the first mmWave TP, a change query requesting the at least one of the change to the communications beam or the mmWave TP change, and receiving from a central controller, by the first mmWave TP, a confirmation message. The method includes updating, by the first mmWave TP, an mmWave UE and second mmWave TPs of the UE centric cloud cell regarding the change.

In accordance with an example embodiment, a method for operating a mmWave UE connected to a cloud cell is provided. The method includes sending, by the mmWave UE, measurement reports of beam-formed reference signals received from mmWave TPs of a measurement set, and receiving, by the mmWave UE, a cloud cell update including updated configuration information for the cloud cell.

In accordance with an example embodiment, a first mmWave TP adapted to perform digital communications is provided. The first mmWave TP includes a processor, and a computer readable storage medium storing programming for execution by the processor. The programming including instructions to configure the first mmWave TP to determine that a change is needed to a configuration of a UE centric cloud cell, where a determining that the change is needed is in accordance with measurement reports of beam-formed reference signals transmitted by mmWave TPs of a measurement set, and when the change comprises a change to a MCS level of a communication link associated with the UE centric cloud cell, adjust the MCS level of the communications link. The programming includes instructions to configure the first mmWave TP to, when the change comprises at least one of a change to a communications beam or a mmWave TP change, send a change query requesting the at least one of the change to the communications beam or the mmWave TP change, and receive a confirmation message. The programming includes instructions to configure the first mmWave TP to update a mmWave UE and second mmWave TPs of the UE centric cloud cell regarding the change.

In accordance with an example embodiment, an mmWave UE adapted to perform digital communications is provided. The mmWave UE includes a processor, and a computer readable storage medium storing programming for execution by the processor. The programming includes instructions to configure the mmWave UE to send measurement reports of beam-formed reference signals received from mmWave TPs of a measurement set, and receive a cloud cell update including updated configuration information for the cloud cell.

Practice of the foregoing embodiments enables the formation of mmWave UE centric cloud cells to improve mmWave operation in a dynamic environment.

Furthermore, the practice of the embodiments enables dynamic adaptation of mmWave UE centric cloud cells with low latency.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present disclosure, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIG. **1** illustrates an example wireless communications system according to example embodiments described herein;

FIG. **2** illustrates an example legacy communications system according to example embodiments described herein;

FIG. **3** illustrates four different deployment scenarios for coordinated multiple point (COMP) transmission for 3GPP LTE Release 11;

FIG. **4** illustrates an example communications system with a large degree of overlap in the coverage areas of TPs in communications system according to example embodiments described herein;

FIG. **5** illustrates a portion of an example communications system including a macro cell legacy communications system with an mmWave communications system overlay according to example embodiments described herein;

FIG. **6** illustrates an example communications system highlighting different types of devices according to example embodiments described herein;

FIGS. **7**A-**7**C illustrate diagrams highlighting messages exchanged and processing occurring in a forming of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **8** illustrates a flow diagram of example operations occurring in an mmWave UE participating in a forming of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **9** illustrates a flow diagram of example operations occurring in a legacy eNB participating in a forming of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **10** illustrates a flow diagram of example operations occurring in a central controller participating in a forming of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **11** illustrates a flow diagram of example operations occurring in a master TP participating in a forming of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **12** illustrates a flow diagram of example operations occurring in a slave TP participating in a forming of an mmWave UE centric cloud cell according to example embodiments described herein;

FIGS. **13**A-**13**D illustrate diagrams highlighting messages exchanged and processing occurring in a forming of an mmWave UE centric cloud cell, highlighting an embodiment technique for handling a situation where an mmWave UE does not receive a RAR from a master TP according to example embodiments described herein;

FIG. **14** illustrates a diagram of example measurement sets in a 3GPP LTE compliant communications system according to example embodiments described herein;

FIGS. **15**A and **15**B illustrate diagrams highlighting messages exchanged and processing occurring in managing an mmWave UE centric cloud cell, highlighting feedback and signaling according to example embodiments described herein;

FIG. **16** illustrates a flow diagram of example operations occurring in an mmWave UE participating in managing an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **17** illustrates a flow diagram of example operations occurring in a master TP participating in managing an mmWave UE centric cloud cell according to example embodiments described herein;

FIGS. **18**A and **18**B illustrate diagrams highlighting first example messages exchanged and processing occurring in changing a master TP of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **19** illustrates a diagram highlighting second example messages exchanged and processing occurring in changing a master TP of an mmWave UE centric cloud cell according to example embodiments described herein;

FIG. **20**A illustrates a flow diagram of example operations occurring in an mmWave UE sending a measurement report according to example embodiments described herein;

FIG. **20**B illustrates a flow diagram of example operations occurring in an mmWave UE participating in a master TP change according to example embodiments described herein;

FIG. **21** illustrates a flow diagram of example operations occurring in a master TP participating in a master TP change according to example embodiments described herein;

FIG. **22** illustrates a flow diagram of example operations occurring in a central controller being informed of a master TP change according to example embodiments described herein;

FIG. **23** illustrates a flow diagram of example operations occurring in a central controller participating in a master TP change when a non-slave mmWave TP becomes a master TP according to example embodiments described herein;

FIGS. **24**A and **24**B illustrate diagrams highlighting messages exchanged and processing occurring in a re-forming of an mmWave UE centric cloud cell, where the mmWave UE remains served by the same central controller after mmWave UE centric cloud cell reformation according to example embodiments described herein;

FIG. **25** illustrates a communications system wherein an mmWave UE is served by a mmWave UE centric cloud cell with mmWave TPs that span multiple legacy eNB coverage areas according to example embodiments described herein;

FIG. **26** illustrates a block diagram of an embodiment processing system for performing methods described herein; and

FIG. **27** illustrates a block diagram of a transceiver adapted to transmit and receive signaling over a telecommunications network according to example embodiments described herein.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The operating of the current example embodiments and the structure thereof are discussed in detail below. It should be appreciated, however, that the present disclosure provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific structures of the embodiments and ways to operate the embodiments disclosed herein, and do not limit the scope of the disclosure.

One embodiment relates to systems and methods for millimeter wave (mmWave) communications. For example, a mmWave UE measures beam-formed reference signals transmitted by a plurality of mmWave transmission points (TPs), sends a cloud cell formation request including indicators associated with best mmWave TPs determined in accordance with the measured beam-formed reference signals, receives a cloud cell formation request response including indicators associated with a subset of the best mmWave TPs selected by a central controller in accordance with selection information, where the subset of the best mmWave TPs includes a first mmWave transmission point (TP) serving as a master TP and a second mmWave TP serving as a slave TP, and establishes a cloud cell with mmWave TPs of the subset of the best mmWave TPs selected by the central controller, where a data connection is established with the slave TP and at least a control connection is established with the master TP.

The embodiments will be described with respect to example embodiments in a specific context, namely communications systems that. The embodiments may be applied to standards compliant communications systems, such as those that are compliant with Third Generation Partnership Project (3GPP), IEEE 802.11, and the like, technical standards, and non-standards compliant communications systems, that.

FIG. **1** illustrates an example wireless communications system **100**. Communications system **100** includes an evolved NodeB (eNB) **105** serving a plurality of user equipments (UEs), such as UE **110**, UE **112**, and UE **114**. In a first operating mode, transmissions for UEs as well as transmissions by UEs pass through the eNB. The eNB allocates network resources for the transmissions to or from the UEs. eNBs may also be commonly referred to as base stations, NodeBs, remote radio heads, access points, and the like, while UEs may also be commonly referred to as mobiles, mobile stations, terminals, subscribers, users, stations, and the like. A base station (or an eNB, NodeB, remote radio head, access point, transmission point, and so on) that is serving one or more UEs may be referred to as a serving base station (SBS). A transmission point may be used to refer to any device capable of transmitting. Therefore, transmission points may refer to eNBs, base stations, NodeBs, remote radio heads, access points, UEs, mobiles, mobile stations, terminals, subscribers, users, and the like.

While it is understood that communications systems may employ multiple eNBs capable of communicating with a number of UEs, only one eNB, and a number of UEs are illustrated for simplicity.

A cell is a commonly used term that refers to a coverage area of an eNB. Typically, a cell is served by one or more sectors of a sectorized antenna of the eNB. Hence, the coverage area of the eNB includes a cell partitioned into a plurality of sectors. As an illustrative example, in a scenario where an eNB uses a three-sector antenna system, the cell of the eNB may be divided into three sectors, with each sector being covered by a separate antenna (with an example beam width of 120 degrees) or a separate part of the total antenna system. As another illustrative example, in a scenario where an eNB uses a six-sector antenna system (where each antenna may cover a 60 degree sector, for example), the cell of the eNB may be divided into six sectors or three sectors, with each sector being covered by one or two antennas or parts sectors of the antenna system respectively.

FIG. **2** illustrates an example legacy communications system **200**. Legacy communications system **200** includes a plurality of legacy eNBs, such as legacy eNB **205**, legacy eNB **207**, and legacy eNB **209**. Each legacy eNB has a corresponding coverage area, e.g., legacy eNB **205** has coverage area **210**, legacy eNB **207** has coverage area **212**, and legacy eNB **209** has coverage area **214**. The legacy eNBs serves UEs, such as legacy eNB **205** serving UE **215**, that are operating in their corresponding coverage areas. Although the coverage areas are shown as hexagons, the coverage areas of each legacy eNB may be irregular in shape, depending upon respective propagation environments.

Coordinated multipoint (COMP) transmission was introduced in 3GPP Long Term Evolution (LTE) Release-11. In COMP transmission, multiple TPs coordinate and transmit data to a UE. FIG. **3** illustrate four different deployment scenarios **300** for COMP transmission in 3GPP LTE

Release-11. Scenario **1 305** covers intra-site collaboration for homogeneous networks and scenario **2 320** covers inter-site collaboration for homogeneous networks. Scenarios **3 340** and **4 360** cover HetNets. Scenario **4 360** is a special case since remote radio heads (RRHs) have the same cell ID as the legacy TP (legacy eNB or high power TP) and form a set of distributed antennas for the high power TP. In order to enable common control signals, such as channel state information reference signal (CSI-RS), demodulation reference signal (DMRS), and so on, a virtual cell ID was introduced. In order to enable reporting from the UEs in a COMP measurement set to different TPs, multiple CSI-RS reporting processes and interference measurement resources (IMR) were introduced in 3GPP LTE Release-11.

FIG. **4** illustrates an example communications system **400** with a large degree of overlap in the coverage areas of TPs in communications system **400**. In general, an extension of COMP (in particular COMP scenario **4 360**), communications system **400** includes TPs with coverage areas that overlap one another to a much greater extent than in previous communications systems. As shown in FIG. **4**, TP**1 405** is located at the outer edges of the coverage areas of its neighboring TPs, such as TP**2 410**, TP**3 415**, TP**4 425**, and so forth. Communications system **400** increases the potential number of UEs involved in collaborative operation (the number of UEs in the COMP measurement sets). As with traditional COMP, a low latency connection between the TPs is needed. Usually, with such a high degree of overlap, each UE, such as UE **420**, can connect to multiple spatially separated TPs with much higher signal to noise ratios (SNRs), such as TP**1 405**, TP**3 415**, and TP**4 425**, than in more conventional systems. The higher SNR connections to spatially separated TPs may enable distributed multiple input multiple output (MIMO) techniques, such as distributed input distributed output (DIDO).

Communications systems with a large degree of overlap in the coverage areas of TPs, such as communications system **400**, rely heavily on low latency high capacity links between the TPs. Although communications systems with a large degree of overlap may be less energy efficient than traditional legacy communications systems, energy efficiency may be realized when no load (or low load) TPs are placed in a sleep mode. The concept of communications systems with a large degree of overlap in the coverage areas of the TPs fits well into the ideas of UE cell centric or UE cloud cell since a set of connected TPs (referred to herein as UE cloud) can follow the UE as it moves through the coverage areas of the communications system. A TP may serve as a central controller that is dynamically assigned to the UE as it moves through the communications system.

In order to achieve increased capacity compared to legacy communications systems, the UE clouds (or sets of connected TPs) are formed from TPs with high SNR connections to a particular UE can perform coordinated scheduling and/or coordinated beam-forming (beam-forming from each TP), dynamic point selection and/or blanking or joint beamforming from all TPs in a DIDO sense. As an illustrative example, TP **405**, TP **415**, and TP **425** form a UE cloud for UE **420**.

A millimeter wave (mmWave) communications system is a communications system that operates in a frequency range where the wavelength of corresponding electromagnetic waves is on the order of a millimeter, which translate to frequencies of about 30 GHz and higher. Other communications systems operate in a frequency range where the wavelength of corresponding electromagnetic waves is on the order of a centimeter (such communications systems may be referred to as cmWave communications systems), which translate to frequencies of about 3 GHz and higher. As with mmWave communications systems, cmWave communications systems typically have fragile communications links that are easily blocked by stationary or moving objects.

Although the discussion focuses on mmWave communications systems and devices therein, the example embodiments presented herein are operable with wireless communications systems operating at any frequency where beamforming is used. Therefore, the discussion of mmWave communications systems should not be construed as being limiting to either the scope or the spirit of the example embodiments.

A prior art technique that have been proposed to help overcome link fragility includes ultra-dense mmWave communications systems where the number of mmWave transmission points (TPs) is sufficiently high so that each UE has the possibility of connecting to multiple spatially separated TPs at the same time. Therefore, even with one or more communications links blocked, the UE may still have one or more unblocked communications links, thereby preserving connectivity.

According to an example embodiment, a communication system with a large degree of overlap in the coverage areas of TPs includes both a legacy communications system and an mmWave communications system. The mmWave communications system overlays the legacy communications system. A legacy UE is served by legacy eNBs that are part of the legacy communications system, while an mmWave UE is served by legacy eNBs of the legacy communications system and mmWave TPs of the mmWave communications system. In other words, the mmWave UEs are served by UE clouds. The inherent spatial diversity provided by the UE clouds (the legacy eNBs and the mmWave TPs) substantially increases the reliability of the TP to mmWave UE connections and protect against blocked paths (link fragility). The low latency high capacity links between the TPs, needed for such communications systems, may be implemented using in-band signaling, such as in the mmWave band, for example. In order to be operable in both the legacy communications system and the mmWave communications system, the mmWave UEs have legacy transceivers and mmWave transceivers.

The mmWave UEs have dual connectivity (control plane and data plane split), meaning that the mmWave UEs may receive control information and data from different TPs (e.g., legacy eNBs and/or mmWave TPs). As an example, an mmWave UE has data plane connectivity with mmWave TPs and control plane connectivity with legacy eNBs. Alternatively, an mmWave UE has data plane connectivity with mmWave TPs and data plane and control plane connectivity with legacy eNBs. Alternatively, an mmWave UE has data plane and control plane connectivity with mmWave TPs and data plane and control plane connectivity with legacy eNBs. Alternatively, an mmWave UE has data plane and control plane connectivity with mmWave TPs and data plane connectivity with legacy eNBs.

FIG. **5** illustrates a portion of an example communications system **500** including a macro cell legacy communications system with an mmWave communications system overlay. The macro cell legacy communications system includes a plurality of full power macro eNBs, however, only macro eNB **505** of the macro cell legacy communications system is shown. Macro cell eNB **505** has a coverage area **507**. The mmWave communications system includes a plurality of mmWave TPs, such as TP **510** (which is located near macro

eNB **505** or is co-located with macro eNB **505**), TP **512**, TP **514**, TP **516**, TP **518**, TP **520**, and TP **522**.

Also shown in FIG. **5** are mmWave UEs, such as mmWave UE **525**, mmWave UE **527**, and mmWave UE **529**. As an illustrative example, mmWave UE **525** receives data from mmWave TP **510**, mmWave TP **514**, and mmWave TP **516**, and control information from mmWave TP **516**. Similarly, mmWave UE **527** receives data from mmWave TP **510**, mmWave TP **512**, and mmWave TP **522**, and control information from macro eNB **505** or mmWave TP **510**; while mmWave UE **529** receives data from mmWave TP **510** and mmWave TP **518**, and control information from mmWave TP **518**.

mmWave UE centric cells may be defined in a virtual sense wherein each mmWave UE sees the set of surrounding TPs (forming an mmWave UE centric cell) as if the set of surrounding TPs was a single TP. The set of surrounding TPs in such a situation may be referred to as a mmWave UE centric virtual cell. According to such a definition, there may be a virtual cell identifier and corresponding virtual control and reference signals associated with the mmWave UE centric virtual cell. The use of such a definition enables the feedback of information to the set of surrounding TPs (the mmWave UE centric virtual cell) with one CSI-RS process. Alternatively, mmWave UE centric cells may also be defined in a non-virtual sense. In such a situation, an mmWave UE sees the TPs in a set of surrounding TPs as different TPs. The set of surrounding TPs in this situation may be referred to as an mmWave UE centric cloud cell.

According to an example embodiment, since mmWave communications require beam-forming to be performed from each TP, different cases of multiple point mmWave transmission are possible in the embodiment communications system, including:

- Spatially separated but connected TPs sending the same data to a UE, which results in increased robustness via spatial diversity; and
- Spatially separated but connected TPs sending different data to a UE, which results in increased data rate via distributed MIMO.

According to an example embodiment, a mmWave UE has transceivers for both the legacy communications system (e.g., 3GPP LTE compliant) and a mmWave communications system that uses beam-forming. The control plane and the data planes are split across the two communications systems.

According to an example embodiment, two control planes, along with associated measurement and management procedures are provided. A first control plane connects an mmWave UE and an mmWave TP to provide fast but fragile connectivity, and a second control plane connects the mmWave UE and a legacy eNB to provide slow but robust connectivity. The associated procedures allow for the initial forming of the mmWave UE centric cloud cells, as well as the managing (i.e., scheduling, maintaining, and updating) of the mmWave UE centric cloud cells. The procedures related to the initial forming of the mmWave UE centric cloud cells specify how the UE performs CSI-RS measurements, and requests a set of mmWave TPs (by specifying beam directions, for example) to be formed into a mmWave UE centric cloud cell. The procedures also specify how a central controller processes the requests (check for interference and/or resource issues, for example) before the mmWave UE centric cloud cell is established. An uplink beam-formed synchronization technique (using a random access channel (RACH) process or otherwise) is also specified. The procedures related to the managing of the mmWave UE centric cloud cells specify ways in which measurements and feedback are handled to reduce latency.

The example embodiments will be described in light of the following considerations:

- The numerology of the mmWave communications system is an integer multiple of the legacy communications system to ensure synchronized measurement reporting between the two communications systems. In other words, a fixed number of mmWave sub-frames times the mmWave sub-frame duration is equal to the legacy sub-frame duration;
- The guard interval of the mmWave communications system is longer than a maximum timing difference from a possible serving mmWave TP in one link direction (either the uplink or the downlink). It is not assumed that the guard interval is longer than the round trip propagation delay since this would lead to too much guard interval overhead for the mmWave communications system. Therefore, each mmWave UE only needs to synchronize itself to a closest and/or strongest TP in each link direction;
- The mmWave TPs are time synchronized; and
- The mmWave TPs and the legacy eNBs are connected using high capacity low latency links, such as optical fiber, mmWave, or next generation front haul interfaces (NGFI) based on mmWave or otherwise.

FIG. **6** illustrates an example communications system **600** highlighting different types of devices. Communications system **600** may be an example of a communication system with a degree of overlap in the coverage areas of TPs. Communications system **600** includes both a legacy communications system and an mmWave communications system. Communications system **600** includes an mmWave UE **605**. Communications system **600** also includes a central controller **610** and a legacy eNB **615**. Central controller **610** has a robust control connection to mmWave UE **605** by way of legacy eNB **615**. Central controller **610** may help to form and manage an mmWave UE centric cloud cell **620** for mmWave UE **605**. Central controller **610** may decide which mmWave TP(s) will be used for each mmWave UE centric cloud cell (in accordance with requested mmWave TPs and communications beams signaled by mmWave UEs, condition of the mmWave TPs (such as load, reliability, interference condition of the mmWave TPs, and the like).

mmWave UE centric cloud cell **620** includes a master TP **625**, and a set of slave TPs, such as slave TP **627**, slave TP **629**, and slave TP **631**. Master TP **625** may decide local scheduling issues, such as modulation coding scheme (MCS) changes, and provides a fast control channel (faster than the robust control connection with legacy eNB **615**). The fast control channel may be used for measurement feedback (from beam-formed CSI-RS, for example), preferred beam direction updates, or when the set of slave TPs needs to be changed. The set of slave TPs provide data connections to enable spatial diversity or increased data rate via distributed MIMO. The set of slave TPs may dynamically be assigned the role of master TP as channel conditions change or as mmWave UE **605** moves about communications system **600**.

Communications system **600** also includes other mmWave TPs that are not part of mmWave UE centric cloud cell **620**, including mmWave TP **633**. Although the other mmWave TPs are not part of mmWave UE centric cloud cell **620** as shown in FIG. **6**, some may become part of mmWave UE centric cloud cell **620** at a later time or may have been part of mmWave UE centric cloud cell **620** in the past.

FIG. **7** illustrates a diagram **700** highlighting messages exchanged and processing occurring in a forming of an mmWave UE centric cloud cell. Diagram **700** illustrates messages exchanged and processing occurring in a legacy eNB **705**, a master TP **710**, one or more slave TPs (e.g., TP2 **715** and TPN **717**), an mmWave UE **720**, and a central controller **725**.

The forming of an mmWave UE centric cloud cell may begin when mmWave UE **720** connects with legacy eNB **705** (event **730**). The connecting with legacy eNB **705** may occur using normal procedures, such as those specified in the 3GPP LTE technical standards. mmWave UE **720** sends a message to legacy eNB **705** informing legacy eNB **705** of the mmWave capabilities of mmWave UE **720** (event **732**). The mmWave capabilities of mmWave UE **720** may include a number of transmit channels, a number of receive channels, and so on. Legacy eNB **705** sends a message signaling a configuration of mmWave TPs within a coverage area of legacy eNB **705** to mmWave UEs, including mmWave UE **720** (event **734**). The configuration may be unicast to mmWave UE **720**, as well as other mmWave UEs operating in the coverage area of legacy eNB **705**. The configuration of the mmWave TPs may include beam-formed BCCH, synchronization channels, reference signal configuration (such as CSI-RS), and so on. Each mmWave TP has unique interference-free beam-formed reference (e.g., synchronization reference signals, channel state information reference signals, and so on) and control signals. The configuration may also include relative mmWave TP position information to reduce the search space of the communications beams.

In accordance with the configuration, mmWave UE **720** measures transmissions made by the mmWave TPs and determines a strongest mmWave TP (block **736**). As an illustrative example, mmWave UE **720** measures a broadcast control channel (BCCH) transmitted by each of the mmWave TPs. mmWave UE **720** synchronizes in the downlink with the strongest mmWave TP, selected in accordance with the measured transmissions (event **738**). mmWave UE **720** synchronizes both in time and frequency with the strongest mmWave TP and the strongest mmWave TP becomes master TP **710**. mmWave UE **720** receives beam-formed CSI-RS from each of the nearby mmWave TPs (events **740-742**). mmWave UE **720** measures the beam-formed CSI-RS from the nearby mmWave TPs using its various receive communications beams and determines best transmit and receive communications beam pairs for each mmWave TP. mmWave UE **720** records an index corresponding to a best beam (or best set of beams) for each mmWave TP.

mmWave UE **720** sends a message with a report of a set of mmWave TPs to legacy eNB **705** (event **744**). mmWave **720** also sends an mmWave UE centric cloud cell formation request (also event **744**). Alternatively, the report of the set of mmWave TPs may serve as an mmWave UE centric cloud cell formation request, with a flag indicating that it is a request, for example. The report of the set of mmWave TPs may include beam indices of the best transmit and receive communications beam pairs for each mmWave TP of the set of mmWave TPs, as well as CQIs for each TP of the set of mmWave TPs. The report of the set of mmWave TPs may include indications of a preferred set of mmWave TPs (with their identifiers) and respective sets of beams and CQIs. It is noted that the preferred set of mmWave TPs may include more mmWave TPs than the number of communications beams that mmWave UE **720** is capable of receiving at any one time. Since mmWave UE **720** is knowledgeable of the periodicity of the beam-formed CSI-RS signals (via the CSI-RS configuration sent in event **734**, for example), mmWave UE **720** may be able to determine that the preferred set of mmWave TPs is changing too rapidly or that the current mobility of mmWave UE **720** is too high (compared to CSI-RS periodicity), mmWave UE **720** may therefore elect to not send the report of the set of mmWave TPs to legacy eNB **705** since reliable mmWave communications may not be maintainable. Therefore, mmWave UE **720** may be able to determine if mmWave connectivity is feasible or not. Legacy eNB **705** forwards the report to central controller **725** (event **746**). mmWave TPs **710-717** report TP capabilities and load information to central controller **725** (events **748**). The reports by mmWave TPs **710-717** may be signaled over the high capacity low latency link.

Central controller **725** determines a set of mmWave TPs for mmWave UE **720**, i.e., a set of mmWave TPs for the mmWave UE centric cloud cell (block **750**). As an illustrative example, central controller **725** may determine the set of mmWave TPs by consulting a central database and considering selection information (i.e., requested communications beams, mmWave TP capabilities, mmWave TP load information, mmWave UE capabilities, interference condition, and so on). Central controller **725** signals information about the set of mmWave TPs to legacy eNB **705** (event **752**). Legacy eNB **705** informs mmWave UE **720** about the set of mmWave TPs (event **754**). Central controller **725** signals mmWave TPs in the set of mmWave TPs to prepare them for mmWave UE **720** (events **756**) and in particular for subsequently receiving beam RACHs from the mmWave UE. Central controller **725** may signal information including transmit and receive communications beam index information to the mmWave TPs based on the best beam indices reported by each UE for each TP in event **744**. The information enables the TPs to more effectively receive the beam-formed RACH from the UE. The signaling may occur over the high capacity low latency link.

mmWave UE **720** starts a beam-formed uplink synchronization procedure (block **758**). The beam-formed uplink synchronization procedure may include mmWave UE **720** initiating a beam-formed RACH with master TP **710** (event **760**). The beam-formed RACH may result in mmWave UE **720** determining uplink transmit power and establishing uplink synchronization with master TP **710**. Master TP **710** sends a beam-formed RACH response (RAR) to mmWave UE **720** (event **762**). Master TP **710** may also send timing advance information to mmWave UE **720** if needed. In an unlikely event that central controller **725** does not assign the strongest mmWave TP to the mmWave UE centric cloud cell, mmWave UE **720** may first synchronize with a master TP assigned by central controller **725** (which is different from the strongest mmWave TP found by mmWave UE **720**), repeat the CSI-RS measurements again and repeat its mmWave UE centric cloud cell formation request with a revised CSI-RS measurement report, with contents that may be similar to the original request in message **744**.

If the beam formed RACH from the UE (event **760**) is successfully received by Master TP **710**, Master TP **710** acknowledges the successful reception via a beam-formed RAR (event **762**) and initiates an acknowledgement from the slave TPs of the set of mmWave TPs, in the order of their reported CQI values from the UE as received in message from event **744**, for example. Master TP **710** initiates an acknowledgement from slave TP **715** (event **764**). Slave TP **715** sends a beam-formed RAR to mmWave UE **720** (event **766**). Master TP **710** initiates an acknowledgement from slave TP **717** (event **768**). Slave TP **717** sends a beam-formed RAR to mmWave UE **720** (event **770**). mmWave UE

720 informs master TP 710 about the RARs received from the slave TPs (event 772). Master TP 710 informs central controller 725 by way of legacy eNB 705 (events 774 and 776), as well as the slave TPs (events 774), about the RARs received by mmWave UE 720. Central controller 725 updates the central database based on information received about the RARs received by mmWave UE 720. Central controller 725 may update a list of TPs assigned to mmWave UE centric cloud cell operation, associated communications beams, and so on (event 778).

Master TP 710 signals mmWave UE 720 information regarding transmission format or parameters (event 780). The transmission format or parameters may include downlink control information (DCI) signaled on a physical downlink control channel (PDCCH). It is noted that different TPs (master TP 710 as well as slave TPs) may have the same or different MCS. The TPs (master TP 710 as well as slave TPs) transmit downlink data to mmWave UE 720 (events 782).

FIG. 8 illustrates a flow diagram of example operations 800 occurring in an mmWave UE participating in a forming of an mmWave UE centric cloud cell. Operations 800 may be indicative of operations occurring in an mmWave UE that is participating in the forming of an mmWave UE centric cloud cell.

Operations 800 begin with the mmWave UE connecting to a legacy communications system (block 805). The mmWave UE may connect to the legacy communications system using one of a variety of techniques, such as those described in the 3GPP LTE technical standards. The mmWave UE receives information about the configuration of reference and control signal for mmWave TPs that are operating within a coverage area of a legacy eNB to which the mmWave UE is connected (block 807).

The mmWave UE measures the signal strength of the mmWave TPs that are operating within the coverage area of the legacy eNB (block 809). The mmWave UE selects the mmWave TP with the strongest signal strength and synchronizes with the mmWave TP (block 811). The mmWave UE scans the other mmWave TPs and records beam indices corresponding to the best transmit and receive communications beams for each of the other mmWave TPs (block 813).

The mmWave UE determines if cloud cell operation is feasible (block 815). As an illustrative example, if there is a sufficient number of mmWave TPs with adequately strong signal strengths, and the received signals from these mmWave TPs are not varying too quickly (indicating that the UE is moving too fast), then cloud cell operation is feasible. If cloud cell operation is not feasible, operations 800 may terminate. If cloud cell operation is feasible, the mmWave UE sends measurement reports for the mmWave TPs to the legacy eNB (block 817). The mmWave UE sends an mmWave UE centric cloud cell formation request to the legacy eNB (block 819). The mmWave UE receives information for a set of mmWave TPs (block 821). The set of mmWave TPs comprises mmWave TPs selected to form the mmWave UE centric cloud cell for the mmWave UE.

The mmWave UE performs uplink synchronization with the master TP (block 823). The uplink synchronization may be initiated with a RACH procedure, for example. The mmWave UE receives a RAR from the master TP of the mmWave UE centric cloud cell (block 825). The mmWave UE receives RARs from the slave TPs in the mmWave UE centric cloud cell (block 827). The mmWave UE reports the received RARs to the master TP (block 829). The mmWave UE receives information regarding a transmission format or parameters (block 831). The forming of the mmWave UE centric cloud cell is complete. Collectively, blocks 809 to 831 comprise the forming of the mmWave UE centric cloud cell (blocks 833). The mmWave UE commences cloud cell communications (block 835).

FIG. 9 illustrates a flow diagram of example operations 900 occurring in a legacy eNB participating in a forming of an mmWave UE centric cloud cell. Operations 900 may be indicative of operations occurring in a legacy eNB as it participates in the forming of a mmWave UE centric cloud cell.

Operations 900 begin with the legacy eNB connecting with an mmWave UE (block 905) using the legacy transceiver contained in the mmWave UE. The legacy eNB sends information about mmWave TPs operating in the coverage area of the legacy eNB to the mmWave UE (block 910). The legacy eNB receives measurement reports from the mmWave UE (block 915). The measurement reports may be signal strength measurements (i.e., RSRP) or channel quality indication reports (CQI) made by the mmWave UE of beam-formed CSI-RS sent by the mmWave TPs. These reports may contain selected beam-index information for each of the selected mmWave TPs and corresponding mmWave TP identifiers. The legacy eNB receives an mmWave UE centric cloud cell formation request from the mmWave UE (block 920). The legacy eNB forwards the mmWave UE centric cloud cell formation request and the measurement reports made by the mmWave UE to a central controller (block 925). The legacy eNB receives a response from the central controller (block 930). The response from the central controller may include information about a set of mmWave TPs selected by the central controller based on the measurement reports made by the mmWave UE. The legacy eNB forwards the response to the mmWave UE (block 935). The legacy eNB receives information about received RARs from the mmWave UE (block 940). The legacy eNB forwards the information about the received RARs to the central controller (block 945).

FIG. 10 illustrates a flow diagram of example operations 1000 occurring in a central controller participating in a forming of an mmWave UE centric cloud cell. Operations 1000 may be indicative of operations occurring in a central controller participating in the forming of an mmWave UE centric cloud cell.

Operations 1000 begin with the central controller receiving an mmWave UE centric cloud cell request and measurement reports (block 1005). The central controller selects mmWave TPs for the mmWave UE centric cloud cell (block 1010). The central controller may select the mmWave TPs in accordance with a central database and selection information (i.e., the requested communications beams, mmWave TP capabilities, mmWave TP load, mmWave UE capabilities, interference condition, and so on). The central controller sends a response to the mmWave UE centric cloud cell formation request to a legacy eNB (block 1015). The response may include information about the mmWave TPs selected by the central controller. The central controller also informs a master TP to expect a RACH on a specified communications beam direction and slave TPs communications beam directions for sending RARs (block 1015). The central controller receives a message with information regarding RARs received by the mmWave UE (block 1020). The central controller updates the central database in accordance with the information regarding the RARs received by the mmWave UE (block 1025).

FIG. 11 illustrates a flow diagram of example operations 1100 occurring in a master TP participating in a forming of an mmWave UE centric cloud cell. Operations 1100 may be

indicative of operations occurring in a master TP participating in the forming of an mmWave UE centric cloud cell.

Operations **1100** begin with the master TP transmitting reference and control signals (block **1105**). The reference and control signals may be beam-formed, such as beam-formed CSI-RS. The master TP sends a message to a central controller informing the central controller the capabilities and load information of the master TP (block **1110**). The master TP receives a message informing the master TP about communications beam directions for an expected RACH reception from an mmWave UE and for transmitting a RAR (block **1120**). The master TP receives an uplink RACH and participates in uplink synchronization with the mmWave UE (block **1125**). The master TP sends a RAR (block **1130**). The master TP receives a report from the mmWave UE of the received RARs from the slave TPs (block **1135**). The master TP commences mmWave UE centric cloud cell communications (block **1140**).

FIG. **12** illustrates a flow diagram of example operations **1200** occurring in a slave TP participating in a forming of an mmWave UE centric cloud cell. Operations **1200** may be indicative of operations occurring in a slave TP participating in the forming of an mmWave UE centric cloud cell.

Operations **1200** begin with the slave TP transmitting reference and control signals (block **1205**). The reference and control signals may be beam-formed, such as beam-formed CSI-RS. The slave TP sends a message to a central controller informing the central controller the capabilities and load information of the slave TP (block **1210**). The slave TP receives a message informing the slave TP about a direction of a communications beam for transmitting a RAR (block **1215**). The slave TP receives a message informing the slave TP that a RACH has been received at a master TP and timing information for sending a RAR (block **1220**). The slave TP sends the RAR (block **1225**). The slave TP commences mmWave UE centric cloud cell communications (block **1230**).

A situation may arise where the mmWave UE does not receive a RAR from the master TP of the mmWave UE centric cloud cell after the mmWave UE sends a RACH to determine an uplink transmit power level and perform uplink synchronization. If the mmWave UE does not receive a RAR from the master TP after a specified number of attempts or after a timeout timer expires, several example embodiments provide solutions for the mmWave UE.

According to an example embodiment, the mmWave UE repeats the measurement of the beam-formed CSI-RS and sends another mmWave UE centric cloud cell formation request to the legacy eNB. As an example, the mmWave UE repeats event **744** shown in FIG. **7**.

According to an example embodiment, the mmWave UE informs the legacy eNB that it has not received a RAR from the master TP and initiates the selection of a different master TP. The selection of the different master TP may be based on the same beam-formed CSI-RS measurements made by the mmWave UE and the different master TP may be the next available mmWave TP selected by the mmWave UE as a member of the preferred set of mmWave TPs with the highest signal measurement.

FIG. **13** illustrates a diagram **1300** highlighting messages exchanged and processing occurring in a forming of an mmWave UE centric cloud cell, highlighting an embodiment technique for handling a situation where an mmWave UE does not receive a RAR from a master TP. Diagram **1300** illustrates messages exchanged and processing occurring in a legacy eNB **1305**, a master TP **1310**, one or more slave TPs (e.g., TP**2** **1315** and TPN **1317**), an mmWave UE **1320**, and a central controller **1325**.

The messages exchanged and processing occurring in the forming of the mmWave UE centric cloud cell as shown in FIG. **13** proceeds in a manner similar to those shown in FIG. **7** until after mmWave UE **1320** sends a RACH to master TP **1310** (event **1330**). If mmWave UE **1320** determines that it has not received a RAR from master TP **1310** after a specified number of attempts or if a timeout timer expires (block **1332**), mmWave UE **1320** sends a message to legacy eNB **1305** indicating that it has not received a RAR from master TP **1310** (event **1334**). Legacy eNB **1305** forwards the message to central controller **1325** (event **1336**). Central controller **1325** receives mmWave TP capability and load information from the mmWave TPs operating in its coverage area (events **1338**). Central controller **1325** selects a new set of mmWave TPs for mmWave UE **1320** and sends information about the new set of mmWave TPs to legacy eNB **1305** (event **1342**) which forwards the information to mmWave UE **1320** (event **1344**). As an illustrative example, central controller **1325** may determine the set of mmWave TPs by consulting a central database and considering requested communications beams, mmWave TP capabilities, mmWave TP load, mmWave UE capabilities, interference, and so on.

Central controller **1325** signals mmWave TPs in the set of mmWave TPs to prepare them for mmWave UE **1320** (events **1346**). Central controller **1325** may signal information including transmit and receive communications beam information. The signaling may occur over the high capacity low latency link. mmWave UE **1320** repeats the beam-form uplink synchronization procedure (block **1348**), by sending a beam-formed RACH to the new master TP, which is shown in FIG. **13** as mmWave TP **1315** (event **1350**).

It may be necessary to manage an mmWave UE centric cloud cell after it has been formed. Management of the mmWave UE centric cloud cell includes: changing transmission format or parameters, changing master TP, adding slave TPs, removing slave TPs, dissolving the mmWave UE centric cloud cell, changing central controller for the mmWave UE centric cloud cell, and so on.

According to an example embodiment, techniques for managing mmWave UE centric cloud cells are provided. According to an example embodiment, feedback and signaling mechanisms are provided.

In order to discuss the management of mmWave UE centric cloud cells, a variety of different sets of mmWave TPs for mmWave UEs are defined as follows:

- Set A: Set of mmWave TPs that are within the mmWave UE's synchronization window. Set A mmWave TPs are mmWave TPs that the mmWave UE can detect (i.e., the channels between these mmWave TPs and the mmWave UE have sufficient SNR) in the current guard interval of the mmWave UE, so that the beam-formed CSI-RS of the relevant mmWave TPs can be received;
- Set B: Set of CSI-RS reporting mmWave TPs (e.g., CQI, beam index (BI), rank indicator (RI) from the CSI-RS measurements). Set B mmWave TPs are the mmWave TPs that the mmWave UE measures and reports in the CSI-RS measurement reports. Set B is a subset of Set A. The members of Set B will be mmWave TPs that meet certain parameters of the CSI-RS configuration (e.g., maximum number of reported mmWave TPs, minimum SNR or CQI of a TP, and so on). The CSI-RS configuration may be independently set for reports sent to the legacy eNB and the master TP. The mmWave UE

may decide which members of Set A are also in Set B subject to the constraints of the CSI-RS configuration. and

Set C: Set C is a subset of Set B. Set C represents a current set of mmWave TPs which are involved in control and/or data communications with the mmWave UE. The master TP and the central controller may determine which members of Set B are in Set C.

In a 3GPP LTE compliant communications system, a legacy UE is configured through radio resource control (RRC) messages to report radio resource measurements (RRM) of TPs in the RRM set. The RRMs are used by network-side entities (e.g., eNBs, controllers, and so on) to determine which TPs will be in a COMP measurement set. FIG. **14** illustrates a diagram **1400** of example measurement sets in a 3GPP LTE compliant communications system. A RRM measurement set **1405** includes TPs, such as TPs **1410**-**1414**, deployed within the general vicinity of a legacy UE **1420**. Legacy UE **1420** measures transmissions made by the TPs, e.g., cell specific reference signals (CRS), and reports RRMs to a network-side entity, such as TP **1410** (a legacy eNB). A COMP measurement set **1425** comprises TPs, such as TP **1410**, TP **1412**, and TP **1413**, that are members of RRM measurement set **1405** that have been selected by a network-side entity (in accordance with their respective RRM reports, for example) as candidates for COMP operation with legacy UE **1420**. The TPs in COMP measurement set **1425** transmit CSI-RS to enable legacy UE **1420** to make measurements. COMP measurement set **1425** may be similar to Set B defined above (except with the proposed approach the mmWave UE decides which TPs are part of this set as opposed to the network-side entities in 3GPP LTE compliant communications systems). A COMP cooperation set **1430** comprises TPs, such as TP **1410** and TP **1412**, that have been selected by a network-side entity (in accordance with their respective CSI-RS measurements) to participate in COMP operations with legacy UE **1420**. COMP cooperation set **1430** may be similar to Set C defined above.

According to an example embodiment, each mmWave UE will determine by itself which mmWave TPs will be in Set B (Set of CSI-RS reporting mmWave TPs) which is in contrast to 3GPP LTE. Self-determination of Set B by the mmWave UEs enables operation with reduced latency.

According to an example embodiment, mmWave UEs monitor synchronization signals of surrounding mmWave TPs and the CSI-RSs of the mmWave TPs that are within its synchronization window or guard time, i.e., Set A members. The regular monitoring of the synchronization signals and the beam-formed CSI-RSs enable the mmWave TPs to provide feedback and signaling with low latency, thereby support the rapidly changing environment inherent in mmWave communications systems. Furthermore, the large uplink bandwidth typically available in mmWave communications systems is exploited to enhance performance. As an illustrative example, the mmWave UEs provide complete CSI-RS measurement reports for a plurality of mmWave TPs (using the large uplink bandwidth) to facilitate fast switching of communications beams and mmWave TPs.

FIG. **15** illustrates a diagram **1500** highlighting messages exchanged and processing occurring in managing an mmWave UE centric cloud cell, highlighting feedback and signaling. Diagram **1500** illustrates messages exchanged and processing occurring in an mmWave UE **1505**, a legacy eNB **1510**, a master TP **1515**, one or more slave TPs (e.g., TP**1**-N) **1520**, an mmWave TPX **1525**, and a central controller **1530**.

After the forming of a mmWave UE centric cloud cell, the composition of the mmWave UE centric cloud cell is aligned along mmWave UE **1505**, master TP **1515**, and central controller **1530** (event **1535**). mmWave UE **1505** participates in cloud cell communications with master TP **1515** and the one or more slave TPs **1520** (event **1537**). mmWave UE **1505** reports CSI-RS measurements to master TP **1515** (event **1539**). The CSI-RS measurements are of mmWave TPs that are within the synchronization window (or guard time) of mmWave UE **1505**. mmWave UE **1505** may provide a preferred beam index (indices) (BI) and rank indicator (RI) for each mmWave TP in the measurement set (i.e., Set B), along with some form of identifier for each mmWave TP. The CSI-RS measurement reports may be signaled periodically according to a specified interval or they may be triggered by mmWave **1505**. The signaling of the CSI-RS measurement reports may take place over the fast uplink control channel with master TP **1515** using the large uplink mmWave bandwidth that is available. There may be a plurality of CSI-RS measurement reporting modes, including:

CQI feedback per mmWave TP (includes mmWave TP identifying information, such as mmWave TP ID) for distributed MIMO operation; and

One CQI feedback (based on an average CQI for the mmWave TPs in set B or just for master TP **1515**) for diversity based operation.

Slave TPs **1520** also report measurement reports of the uplink received signal from the UE to the master TP **1515** (event **1541**).

The CSI-RS status is updated at Master TP **1515**—(CSI-RS status—block **1543**). If the CSI-RS measurement reports indicate that only the assigned MCS for transmissions needs to be changed, master TP **1515** may initiate any associated changes by itself (block **1545**). However, if the CSI-RS measurement reports indicate that the communications beams from the mmWave TPs needs to be changed or if the mmWave UE centric cloud cell needs to be changed, master TP **1515** may need to consult central controller **1530** to support the change (block **1547**).

If master TP **1515** needs to consult central controller **1530**, master TP **1515** sends a change query to central controller **1530** (event **1549**). The change query may be regarding a possible change in the communications beam for a given mmWave TP or the composition of mmWave UE centric cloud cell (i.e, which mmWave TPs are in the cloud cell). If master TP **1515** is directly connected to central controller **1530**, the change query may be sent directly to central controller **1530**. If master TP **1515** is not directly connected to central controller **1530**, the change query may be sent to legacy eNB **1510**, which would serve as intermediary and send the change query to central controller **1530**. Central controller **1530** updates a configuration for the communications beam and/or the mmWave UE centric cloud cell (event **1551**) and sends a confirmation to master TP **1515** (event **1553**). Once again, the confirmation may be sent directly to master TP **1515** or through legacy eNB **1510** depending on connectivity between central controller **1530** and master TP **1515**.

Master TP **1515** schedules communications for the mmWave UE centric cloud cell (event **1555**). If any updates to the mmWave UE centric cloud cell is needed, master TP **1515** updates central controller **1530** (event **1557**) and mmWave TPs, including slave TPs **1520** and mmWave TPX **1525** (event **1559**). The composition of the mmWave UE centric cloud cell is aligned along mmWave UE **1505**, master TP **1515**, and central controller **1530** (event **1561**).

Events and blocks **1539-1561** may be referred to as a CSI-RS monitoring loop **1563**. Media Access Control (MAC) control elements may be used to modify member mmWave TPs of the mmWave UE centric cloud cell.

FIG. **16** illustrates a flow diagram of example operations **1600** occurring in an mmWave UE participating in managing an mmWave UE centric cloud cell. Operations **1600** may be indicative of operations occurring in an mmWave UE participating in managing an mmWave UE centric cloud cell.

Operations **1600** begin with the mmWave UE receiving and decoding reference signals from mmWave TPs (block **1605**). The mmWave UE may receive and decode synchronization signals from mmWave TPs and CSI-RS signals from mmWave TPs that are members of Set A, for example. Since the mmWave UE is downlink synchronized to the master TP, the mmWave UE can receive and decode the beam-formed CSI-RS of the mmWave TPs that are members of Set A. Additionally, the mmWave UE may determine and store a set of preferred receive transmission beam(s) for each mmWave TP. The mmWave TPs in Set A is potentially larger than the set of mmWave TPs to which the mmWave UE is currently connected (Set C) due to limitations in the number of receivers of the mmWave UE or scheduling restraints at the mmWave TPs, for example.

The mmWave UE sends measurement reports to the master TP (block **1610**). The mmWave UE may periodically send the measurement reports as configured or if the mmWave UE notes that a change in the mmWave UE centric cloud set is warranted (based on the measurements) the mmWave UE may trigger the master TP to request an aperiodic measurement report from the mmWave UE by indicating an initiate CSI-RS report request flag in an uplink control signal. In the periodic reporting scenario, if the CQI reporting mode is set to CQI feedback per mmWave TP, the master mmWave TP receives the measurement reports and the central controller determines which mmWave TPs (based on the CQI reports, requested communications beams, mmWave TP availability, operating conditions, and so on) are to be included in an updated mmWave UE centric cloud cell.

The mmWave UE receives information regarding the updated mmWave UE centric cloud cell (block **1615**). The information may include identifiers of the mmWave TPs in the updated mmWave UE centric cloud cell, as well as communications beam information. The mmWave UE commences mmWave UE centric cloud cell communications (block **1620**).

FIG. **17** illustrates a flow diagram of example operations **1700** occurring in a master TP participating in managing an mmWave UE centric cloud cell. Operations **1700** may be indicative of operations occurring in master TP participating in managing an mmWave UE centric cloud cell.

Operations **1700** begin with the master TP receiving measurement reports from the mmWave UE (block **1705**). The measurement reports may be received periodically at regular intervals or the measurement reports may be triggered aperiodically by the mmWave UE. The master TP compares the measurement report to previous measurement reports (block **1710**). If the measurement report has changed significantly, e.g., the CQI of one or more mmWave TPs has changed more than a threshold or a combined CQI for all mmWave TPs has changed more than a threshold, the master TP may determine that a change in the mmWave UE centric cloud cell is warranted. The master TP performs a check to determine if the change is limited to only changing the MCS (block **1715**). If the change is limited to changing only the MCS, the master TP makes the change to the MCS (block **1720**). If the change is not limited to changing only the MCS, for example, a change in communications beam for each mmWave TP or rank, the master TP sends a change query to the central controller and receives a confirmation from the central controller (block **1725**). The change query may include the measurement reports (including CQI, Beam indices, and rank information for the mmWave TPs) and the confirmation may include changes to the mmWave UE centric cloud cell or an updated mmWave UE centric cloud cell.

The master TP schedules using the updated mmWave UE centric cloud cell (block **1730**). If there have been changes to the mmWave TP configuration, the master TP sends a message updating the mmWave TPs regarding the updated mmWave UE centric cloud cell (block **1735**). The master TP commences mmWave UE centric cloud cell communications (block **1740**).

In some situations, it may be necessary to change the master TP of an mmWave UE centric cloud cell. As an illustrative example, if the mmWave UE detects that an mmWave TP that is a member of Set A has a stronger signal, e.g., CQI, than that of the master TP, then it may be desirable to make the mmWave TP the new master TP. As another illustrative example, the the communications channel between the master TP and the mmWave UE may have degraded, the communications channel may be blocked or partially blocked, the master TP may have failed, and so on. Depending upon which set (e.g., Sets A, B or C) the new mmWave TP (with the stronger signal) is in, there will be a different mechanism for making the new TP into a Master TP. For instance, if the newly detected mmWave TP with the stronger signal is in set C (the connected set), the central controller may not need to be first consulted (only subsequently informed), since this TP is already in the cloud cell as a slave TP. If however the new detected mmWave TP, is in Set A or B, the central controller may first need to be consulted since the newly detected mmWave TP is not yet in the connected set and has not yet been assigned to be in the mmWave UE centric cloud cell by the central controller.

FIG. **18** illustrates a diagram **1800** highlighting first example messages exchanged and processing occurring in changing a master TP of an mmWave UE centric cloud cell for the case that the central controller does not need to be first consulted (i.e., this new master TP is already in the connected set C). Diagram **1800** illustrates messages exchanged and processing occurring in an mmWave UE **1805**, a legacy eNB **1810**, a master TP **1815**, one or more slave TPs (e.g., TP**1**-N) **1820**, an mmWave TPX **1825**, and a central controller **1830**.

After the forming of an mmWave UE centric cloud cell, the composition of the mmWave UE centric cloud cell includes master TP **1815** and slave TPs **1820**, including mmWave TPX **1825** (block **1835**). The mmWave UE measures CSI-RS transmissions made by the mmWave TPs of the mmWave UE centric cloud cell (event **1837**) and reports the measurements (event **1839**). As discussed previously, the measurements may be reported periodically at specified intervals. Alternatively, the mmWave UE may trigger a measurement report by setting a an initiate CSI-RS report request flag in an uplink control signal, causing the master TP to ask the mmWave UE for an aperiodic measurement report.

Master TP **1815** determines if central controller **1830** needs to be consulted regarding the master TP change (block **1841**). (i.e., based on the ID of the newly detected mmWave TP, the master TP can determine if the newly detected

mmWave TP is already in the connected set or not). A situation wherein central controller **1830** does not need to be consulted is illustrated in FIG. **18**. If central controller **1830** needs to be consulted, master TP **1815** sends a query to central controller **1830** and central controller **1830** responds with a confirmation with an updated mmWave UE centric cloud cell.

For discussion purposes, consider a situation wherein mmWave TPX **1825** is to become the new master TP. Master TP **1815** and mmWave TPX **1825** negotiates a new master TP role for mmWave TPX **1825** (event **1843**). Master TP **1815** signals to mmWave UE **1805** informing mmWave UE **1805** that mmWave TPX **1825** will become the new master TP (event **1845**). mmWave UE **1805** signals a master TP change response to mmwave TPX **1825** (event **1847**). The master TP change response may confirm the master TP change. mmWave TPX **1825**, now the new master TP, signals an announcement announcing that it is the new master TP (event **1849**). The announcement may be sent to legacy eNB **1810**, which forwards the announcement to central controller **1830**. Central controller **1830** updates all mmWave TPs in the updated mmWave UE centric cloud cell (event **1851**). After the update, the composition of the mmWave UE centric cloud cell is aligned with mmWave UE **1805**, legacy eNB **1810**, central controller **1830**, and the members of the mmWave UE centric cloud cell (block **1853**).

It is noted that in a situation that warrants a master TP change, a communications channel between the master TP and an mmWave UE is likely to be weak or degraded. Although the procedure outlined in FIG. **18** will work, a more robust solution is available.

FIG. **19** illustrates a diagram **1900** highlighting second example messages exchanged and processing occurring in changing a master TP of an mmWave UE centric cloud cell. Diagram **1900** illustrates messages exchanged and processing occurring in an mmWave UE **1905**, a legacy eNB **1910**, a master TP **1915**, one or more slave TPs (e.g., TP1-N) **1920**, and an mmWave TPX **1925**.

The messages exchanged and processing shown in FIG. **19** may be representative of events occurring after master TP **1915** has determined that a master TP change should take place and master TP **1915** has negotiated the master TP change with mmWave TPX **1925**. As an illustrative example, the messages exchanged and processing shown in FIG. **19** may occur after event **1843** of FIG. **18** and before event **1849** of FIG. **18**.

Master TP **1915** sends a master TP change message to legacy eNB **1910** (event **1930**). Since master TP **1915** and legacy eNB **1910** communicate via a high throughput low latency link, the condition of the link is very reliable. Legacy eNB **1910** forwards the master TP change message to mmWave UE **1905** via the legacy (i.e. via LTE) link (event **1932**) which is much more reliable than the degraded (or potentially non-existent) mmWave link between mmWave master TP **1915** and mmWave UE **1905**. mmWave UE **1905** signals a master TP change response to mmwave TPX **1925** (event **1934**). The master TP change response may confirm the master TP change.

FIG. **20**A illustrates a flow diagram of example operations **2000** occurring in an mmWave UE sending a measurement report. Operations **2000** may be indicative of operations occurring in an mmWave UE sending a measurement report.

Operations **2000** begin with the mmWave UE receiving and decoding reference signals from mmWave TPs to measure the reference signals from TPs in Set A (block **2005**). The mmWave UE performs a check to determine if it is time to report the measured reference signals (block **2010**). In other words, is it time to make a periodic measurement report. If it is not time to report the measured reference signals, the mmWave UE performs a check to determine if it needs to report the measured reference signals (block **2015**). As an illustrative example, the mmWave UE may determine that there needs to be a change in the communications beam direction, a change in the MCS for the present transmissions, and so on.

If there is a need to report the measured reference signals, the mmWave UE initiates an aperiodic measurement report request (block **2020**). As an illustrative example, the mmWave UE triggers an aperiodic measurement report request by indicating an initiate CSI-RS report request flag in an uplink control signal. In this way, the example embodiments can reduce the latency associated with feeding back information, since in traditional communications systems, aperiodic measurement reports are normally triggered only by a serving TP. The mmWave UE performs a check to determine if it has received an aperiodic report request from the Master TP (block **2025**). If the mmWave UE has not received a report request, the mmWave UE may continue to wait for the report request (by returning to block **2025**) or operations **2000** may terminate, depending on implementation. If the mmWave UE has received a report request, the mmWave UE sends a measurement report (block **2030**). If the measure reference signal for one of the measured mmWave TPs is not better than the measured reference signal for the master TP (or if none of the other feedback parameters have changed), then operations **2000** may terminate. If it is time to report the measured reference signals (block **2010**), the mmWave UE sends a measurement report (block **2030**).

FIG. **20**B illustrates a flow diagram of example operations **2050** occurring in an mmWave UE participating in a master TP change. Operations **2000** may be indicative of operations occurring in an mmWave UE participating in a master TP change.

Operations **2050** begin with the mmWave UE sending a measurement report (block **2055**). The mmWave UE receives a master TP change request (block **2060**). The master TP change request may be received from the master TP or from the legacy eNB. The mmWave UE sends a master TP change response to an mmWave TP that will become the new master TP and synchronizes to the new Master TP (block **2065**). The mmWave UE commences mmWave UE centric cloud cell communications (block **2070**).

FIG. **21** illustrates a flow diagram of example operations **2100** occurring in a master TP participating in a master TP change. Operations **2100** may be indicative of operations occurring in a master TP participating in a master TP change.

Operations **2100** begin with the master TP receiving a measurement report from the mmWave UE (block **2105**). The measurement report may be a regular periodic measurement report or the measurement report may be an aperiodic report triggered by the master TP after receiving uplink control information with an initiate CSI-RS report request flag that is set to a specified value. The master TP performs a check to determine if the mmWave TP that will become the new master TP is part of the mmWave UE centric cloud cell (block **2110**). If the mmWave TP is part of the mmWave UE centric cloud cell, the master TP and the mmWave TP participate in a handover and the mmWave TP becomes the new master TP (block **2115**). It is noted that if the communications beam(s) need to change, the central controller may

need to be consulted even if the mmWave TP is part of the mmWave UE centric cloud cell.

If the mmWave TP is not part of the mmWave UE centric cloud cell, the master TP sends a change request to the central controller to determine if the mmWave TP is available (block **2120**). The master TP receives a response from the central controller (block **2125**). After the handover has been completed or after receiving the response from the central controller, the former master TP sends a master TP change request to the mmWave UE to inform the mmWave UE about the master TP change (block **2130**). The former master TP commences mmWave UE centric cloud cell communications (block **2135**).

FIG. **22** illustrates a flow diagram of example operations **2200** occurring in a central controller being informed of a master TP change. Operations **2200** may be indicative of operations occurring in a central controller being informed of a master TP change when a slave TP becomes a master TP.

Operations **2200** begin with the central controller receiving a new master TP announcement (block **2205**). The new master TP may be received from the new master TP of the mmWave UE centric cloud cell. The central controller updates information about the mmWave UE centric cloud cell (block **2210**). The information may be stored in a database. The central controller sends information about the updated mmWave UE centric cloud cell (block **2215**). The information about the updated mmWave UE centric cloud cell may be sent to the member mmWave TPs of the updated mmWave UE centric cloud cell.

FIG. **23** illustrates a flow diagram of example operations **2300** occurring in a central controller participating in a master TP change when a non-slave mmWave TP becomes a master TP. Operations **2300** may be indicative of operations occurring in a central controller participating in a master TP change. The non-slave TP subsequently becomes a new master TP.

Operations **2300** begin with the central controller receiving a request to have a newly found mmWave TP become a master TP (block **2305**). The newly found mmWave TP in this instance is a non-slave TP. In other words, the newly found mmWave TP is not a member of the mmWave UE's mmWave UE centric cloud cell. The central controller, may select the mmWave TPs in accordance with a central database and selection information (i.e., the requested communications beams, mmWave TP capabilities, mmWave TP load, mmWave UE capabilities, interference condition, and so on) (block **2310**). The central controller updates information about the mmWave UE centric cloud cell (block **2315**). The central controller sends the updated information (block **2320**). The update information may be sent to the mmWave UE, as well as the members of the mmWave UE centric cloud cell. The central controller updates information in the central database regarding the mmWave UE centric cloud cell (block **2325**).

As discussed previously, a mmWave UE may be configured to provide either one CQI feedback per reported mmWave TP (i.e., Set B) or one CQI feedback for the mmWave TPs (where the average CQI is for all of the reported mmWave TPs (i.e., Set B), all of the mmWave TPs in the connected set (i.e., Set C), or another set of mmWave TPs determined by the master TP). It is noted that when the mmWave UE is configured to perform one CQI feedback for the mmWave TPs, the final transmission will be a diversity type transmission with the mmWave TPs sending the same data stream and using the same MCS. However, if the mmWave UE is configured to perform one CQI feedback per mmWave TP, the UE may select communications beams for the mmWave TPs (i.e., using the beam-index (BI) in the CSI-RS measurement report) for downlink transmission which are received using the same receive communications beams at the mmWave UE. When this occurs, the mmWave TPs should not use classic distributed MIMO transmission since the mmWave UE may not be able to distinguish the different signals sent at the same time and frequency from the mmWave TPs. Therefore, the mmWave UE measurement report may include a one bit transmission mode flag where:

- '0'—Mode 0—transmit diversity or transmit distributed MIMO on different subbands,
- '1'—Mode 1—classic distributed MIMO (same subband).

To indicate what the transmission mode should be for the beam indices which it has feedback to the master TP.

Since mmWave links are fragile and in high mobility situations, the mmWave UE (or legacy eNB) may choose to drop mmWave connectivity altogether and use only legacy communications, (i.e., LTE) situations may arise when a smooth master TP change may not possible.

A number of scenarios are considered:

The mmWave UE is in a completely different coverage area and the responsible central controller for this new coverage area is different from the central controller of the coverage area where the mmWave UE was last connected at mmWave frequencies. In this scenario, the mmWave UE centric cloud cell may need to be configured totally from the beginning again using an mmWave UE centric cloud cell formation request, as illustrated in FIG. **7**.

The mmWave UE is still served by the same central controller. In order to quickly re-establish the mmWave UE centric cloud cell, the mmWave UE may send a control link failure report and send a mmWave UE centric cloud cell re-formation request over the legacy uplink control channel so that the mmWave UE centric cloud cell can be quickly re-formed using the most recently saved data at the central controller (or central database). If the mmWave UE provides additional information in the control link failure report, the central controller may make an intelligent decision as to how to re-form the mmWave UE centric cloud cell in accordance with previous measurements.

FIG. **24** illustrates a diagram **2400** highlighting messages exchanged and processing occurring in a re-forming of an mmWave UE centric cloud cell, where the mmWave UE remains served by the same central controller after mmWave UE centric cloud cell reformation. Diagram **2400** illustrates messages exchanged and processing occurring in a legacy eNB **2405**, a master TP **2410**, one or more slave TPs (e.g., TP**2** **2415** and TPN **2417**), an mmWave UE **2420**, and a central controller **2425**.

mmWave UE **2420** determines that an mmWave link has failed and sends a mmWave link failure report (event **2430**). The mmWave link may have failed if the received mmWave signal quality from the Master TP drops below a specified threshold (before a hand over to a new Master TP can complete), if the mmWave TP (i.e., the master TP) fails, the UE moves out of range, and so on, for example. The mmWave link failure report may include an identifier, e.g., mmWave TP ID, of the mmWave TP whose link failed (i.e., failed Master TP) (if known), an identifier (ID) of a mmWave TP to which the TP is currently down linked synchronized with (effectively the new Master TP for that UE), and so on. If mmWave UE **2420** provides the identifier of the synchronized mmWave TP and any information

regarding the mmWave TP where control connectivity was lost in the mmWave link failure report, a new mmWave UE centric cloud cell may be quickly re-established. The mmWave link failure report may be sent to legacy eNB **2405**, which forwards the mmWave link failure report to central controller **2425**. The mmWave UE **2420** sends an mmWave UE centric cloud cell reformation request (event **2432**). The mmWave UE centric cloud cell reformation request may be sent to central controller **2425**. Central controller **2425** will be informed of all of the mmWave TPs capability and load information (event **2434**) to which it is connected to, or to which it is serving.

Central controller **2425** selects a new mmWave UE centric cloud cell for mmWave UE **2420** (block **2436**). The new mmWave UE centric cloud cell may be formed in accordance with the mmWave TP capabilities and load information provided by the mmWave TPs. The new mmWave UE centric cloud cell may also be formed in accordance with the mmWave TPs in the previous mmWave UE centric cloud cell, as well as information included in the wwWave link failure report and saved CSI-RS measurement reports from mmWave UE. Central controller **2425** sends mmWave UE **2420** (by way of legacy connection (i.e., LTE) to eNB **2405**) a message informing mmWave UE **2420** information about the new mmWave UE centric cloud cell formed (event **2438**). Central controller **2425** prepares the mmWave TPs in the new mmWave UE centric cloud cell for communications with mmWave UE **2420** (events **2440**).

mmWave UE **2420** starts a beam-formed uplink synchronization procedure (event **2442**). The beam-formed uplink synchronization procedure may include mmWave UE **2420** initiating a beam-formed RACH with master TP **2410** (event **2444**). The beam-formed RACH may result in mmWave UE **2420** determining uplink transmit power and establishing uplink synchronization with master TP **2410**. If the beam-formed RACH is correctly received at the Master TP **2410**, the Master TP sends a beam-formed RAR to mmWave UE **2420** (event **2446**). Master TP **2410** may also send timing advance information to mmWave UE **2420** if needed. In an unlikely event that central controller **2425** does not assign the strongest mmWave TP to the mmWave UE centric cloud cell, mmWave UE **2420** may first synchronize with a master TP assigned by central controller **2425** (which is different from the strongest mmWave TP found by mmWave UE **2420**, repeat the CSI-RS measurements and repeat its mmWave UE centric cloud cell formation request or may follow the procedure illustrated in FIG. **13**.

Master TP **2410** correctly receives a beam-formed RACH from the mmWave UE, it initiates an acknowledgement from the slave TPs of the set of mmWave TPs in the order that the CQI knowledge of the different TP is stored at the central controller Master TP **2410** initiates an acknowledgement from slave TP **2415** (event **2448**). Slave TP **2415** then sends a beam-formed RAR to mmWave UE **2420** (event **2450**). Master TP **2410** then initiates an acknowledgement from slave TP **2417** (event **2452**). Slave TP **2417** then sends a beam-formed RAR to mmWave UE **2420** (event **2454**). mmWave UE **2420** informs master TP **2410** about the RARs received from the slave TPs (event **2456**). Master TP **2410** informs central controller **2425** by way of legacy eNB **2405** (events **2458**), as well as the slave TPs (events **2458**), about the RARs received by mmWave UE **2420**. Central controller **2425** updates the central database based on information received about the RARs received by mmWave UE **2420**. Central controller **2425** may update a list of TPs assigned to mmWave UE centric cloud cell operation, associated communications beams, and so on (event **2460**).

Master TP **2410** signals mmWave UE **2420** information regarding transmission format or parameters (event **2462**). The transmission format or parameters may include DCI signaled on a PDCCH. It is noted that different TPs (master TP **2410** as well as slave TPs) may have the same or different MCS. The TPs (master TP **2410** as well as slave TPs) transmit downlink data to mmWave UE **2420** (events **2464**).

In general, a central controller controls the mmWave TPs operating in the coverage area of at least one legacy eNB. However, if a central controller is able to control a set of mmWave TPs that span the coverage areas of a plurality of legacy eNBs, issues arising when mmWave TPs of an mmWave UE centric cloud cell span multiple legacy eNB boundaries and when control channels are located in different legacy eNB coverage areas do not occur. FIG. **25** illustrates a communications system **2500** wherein an mmWave UE is served by a mmWave UE centric cloud cell with mmWave TPs that span multiple legacy eNB coverage areas. As shown in FIG. **25**, mmWave UE **2505** is receiving a first control channel from legacy eNB **2510**, a second control channel from mmWave TP **2515**, and data from mmWave TP **2515**, mmWave TP **2520**, and mmWave TP **2522**. The mmWave UE centric cloud cell spans the coverage areas of two legacy eNBs. In order to facilitate mmWave UE centric cloud cell operation across legacy eNB coverage areas, mmWave TPs across eNB coverage areas will be connected. However, the contents of the central controller associated with each mmWave UE may have to be moved (copied) over to the adjacent central controller when the mmWave UE centric cloud cell is served by the new central controller (the adjacent central controller). The handover from one central controller to another should be independent of a normal legacy eNB to legacy eNB handover.

According to an example embodiment, the fast control channel link (either uplink or downlink or both) may be transported between the mmWave UE and more than one of the mmWave TPs of the mmWave UE centric cloud cell, as opposed to just using the Master mmWave TP. The fast control channel link being received and/or sent by more than one mmWave TP offers the benefits of spatial diversity to the fast control channel, making the fast control channel more immune to link fragility.

According to an example embodiment, in the situation wherein a fast uplink control channel link to more than mmWave TPs of the mmWave UE centric cloud cell is implemented, the multiple uplink control channels are combined at a single mmWave TP, e.g., the master TP.

According to an example embodiment, in the situation wherein a fast downlink control channel link from more than mmWave TPs of the mmWave UE centric cloud cell is implemented, the multiple downlink control channels are combined at the mmWave UE.

FIG. **26** illustrates a block diagram of an embodiment processing system **2600** for performing methods described herein, which may be installed in a host device. As shown, the processing system **2600** includes a processor **2604**, a memory **2606**, and interfaces **2610**-**2614**, which may (or may not) be arranged as shown in FIG. **26**. The processor **2604** may be any component or collection of components adapted to perform computations and/or other processing related tasks, and the memory **2606** may be any component or collection of components adapted to store programming and/or instructions for execution by the processor **2604**. In an embodiment, the memory **2606** includes a non-transitory computer readable medium. The interfaces **2610**, **2612**, **2614** may be any component or collection of components that allow the processing system **2600** to communicate with

other devices/components and/or a user. For example, one or more of the interfaces **2610**, **2612**, **2614** may be adapted to communicate data, control, or management messages from the processor **2604** to applications installed on the host device and/or a remote device. As another example, one or more of the interfaces **2610**, **2612**, **2614** may be adapted to allow a user or user device (e.g., personal computer (PC), etc.) to interact/communicate with the processing system **2600**. The processing system **600** may include additional components not depicted in FIG. **26**, such as long term storage (e.g., non-volatile memory, etc.).

In some embodiments, the processing system **2600** is included in a network device that is accessing, or part otherwise of, a telecommunications network. In one example, the processing system **2600** is in a network-side device in a wireless or wireline telecommunications network, such as a base station, a relay station, a scheduler, a controller, a gateway, a router, an applications server, or any other device in the telecommunications network. In other embodiments, the processing system **2600** is in a user-side device accessing a wireless or wireline telecommunications network, such as a mobile station, a user equipment (UE), a personal computer (PC), a tablet, a wearable communications device (e.g., a smartwatch, etc.), or any other device adapted to access a telecommunications network.

In some embodiments, one or more of the interfaces **2610**, **2612**, **2614** connects the processing system **2600** to a transceiver adapted to transmit and receive signaling over the telecommunications network. FIG. **27** illustrates a block diagram of a transceiver **2700** adapted to transmit and receive signaling over a telecommunications network. The transceiver **2700** may be installed in a host device. As shown, the transceiver **2700** comprises a network-side interface **2702**, a coupler **2704**, a transmitter **2706**, a receiver **2708**, a signal processor **2710**, and a device-side interface **2712**. The network-side interface **2702** may include any component or collection of components adapted to transmit or receive signaling over a wireless or wireline telecommunications network. The coupler **2704** may include any component or collection of components adapted to facilitate bi-directional communication over the network-side interface **2702**. The transmitter **2706** may include any component or collection of components (e.g., up-converter, power amplifier, etc.) adapted to convert a baseband signal into a modulated carrier signal suitable for transmission over the network-side interface **2702**. The receiver **2708** may include any component or collection of components (e.g., down-converter, low noise amplifier, etc.) adapted to convert a carrier signal received over the network-side interface **2702** into a baseband signal. The signal processor **2710** may include any component or collection of components adapted to convert a baseband signal into a data signal suitable for communication over the device-side interface(s) **2712**, or vice-versa. The device-side interface(s) **2712** may include any component or collection of components adapted to communicate data-signals between the signal processor **2710** and components within the host device (e.g., the processing system **2600**, local area network (LAN) ports, etc.).

The transceiver **2700** may transmit and receive signaling over any type of communications medium. In some embodiments, the transceiver **2700** transmits and receives signaling over a wireless medium. For example, the transceiver **2700** may be a wireless transceiver adapted to communicate in accordance with a wireless telecommunications protocol, such as a cellular protocol (e.g., long-term evolution (LTE), etc.), a wireless local area network (WLAN) protocol (e.g., Wi-Fi, etc.), or any other type of wireless protocol (e.g., Bluetooth, near field communication (NFC), etc.). In such embodiments, the network-side interface **2702** comprises one or more antenna/radiating elements. For example, the network-side interface **2702** may include a single antenna, multiple separate antennas, or a multi-antenna array configured for multi-layer communication, e.g., single input multiple output (SIMO), multiple input single output (MISO), multiple input multiple output (MIMO), etc. In other embodiments, the transceiver **2700** transmits and receives signaling over a wireline medium, e.g., twisted-pair cable, coaxial cable, optical fiber, etc. Specific processing systems and/or transceivers may utilize all of the components shown, or only a subset of the components, and levels of integration may vary from device to device.

Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the appended claims.

What is claimed is:

1. A computer-implemented method for operating a millimeter wave (mmWave) user equipment (UE), the method comprising:

detecting, by the mmWave UE, a failed mmWave link between the mmWave UE and a first mmWave transmission point (TP) serving the mmWave UE, and based thereon:

sending, by the mmWave UE, a cloud cell reformation request,

receiving, by the mmWave UE, information about a second mmWave TP and a third mmWave TP, and

establishing, by the mmWave UE, a reformed cloud cell with the second mmWave TP and the third mmWave TP, where a data connection is established with the third mmWave TP and at least a control connection is established with the second mmWave TP, the establishing the reformed cloud cell comprising:

sending, by the mmWave UE, a beam-formed random access channel (RACH) to the second mmWave TP,

receiving, by the mmWave UE, a first beam-formed RACH response (RAR) from the second mmWave TP, thereby forming the control connection with the second mmWave TP,

receiving, by the mmWave UE, a second beam-formed RAR from the third mmWave TP,

sending, by the mmWave UE to the second mmWave TP, information about the beam-formed RARs, and

receiving, by the mmWave UE from the second mmWave TP, information about transmission parameters of a mmWave link with the reformed cloud cell.

2. The method of claim **1**, further comprising sending, by the UE, a mmWave link failure report when the failed mmWave link is detected.

3. The method of claim **2**, wherein the mmWave link failure report comprises at least one of an identifier of the first mmWave TP, or an identifier of a fourth mmWave TP to which the mmWave UE is synchronized with.

4. The method of claim **2**, wherein the mmWave link failure report is sent to a legacy evolved NodeB (eNB).

5. The method of claim **1**, further comprising, prior to detecting the failed mmWave link, establishing a cloud cell with at least the first mmWave TP.

6. The method of claim 1, wherein the mmWave UE is simultaneously connected to a legacy eNB and to the second mmWave TP.

7. A computer-implemented method for operating a central controller, the method comprising:

receiving, by the central controller, a millimeter wave (mmWave) link failure report from a mmWave user equipment (UE), the mmWave link failure report reporting failure of a mmWave link between the mmWave UE and a first mmWave TP;

receiving, by the central controller, a cloud cell reformation request from the mmWave UE;

receiving, by the central controller, information about beam-formed random access channel responses (RARs) received by the mmWave UE;

selecting, by the central controller, a second mmWave transmission point (TP) and a third mmWave TP from a plurality of mmWave TPs, the selecting the second mmWave TP and the third mmWave TP being in accordance with mmWave TP capability information and mmWave TP load information;

preparing, by the central controller, the second mmWave TP and the third mmWave TP for communications with the mmWave UE; and

sending, by the central controller, information about the second mmWave TP and the third mmWave TP to the mmWave UE.

8. The method of claim 7, wherein preparing the second mmWave TP and the third mmWave TP comprises sending communications beam information to the second mmWave TP and the third mmWave TP.

9. The method of claim 7, further comprising prior to selecting the second mmWave TP and the third mmWave TP, receiving, by the central controller, the mmWave TP capability information and the mmWave TP load information from the plurality of mmWave TPs.

10. The method of claim 7, wherein the second mmWave TP and the third mmWave TP are also selected in accordance with information about a cloud cell associated with the mmWave link, wherein the cloud cell includes the first mmWave TP.

11. A millimeter wave (mmWave) user equipment (UE) comprising:

a non-transitory memory storage comprising instructions; and

one or more processors in communication with the memory storage, wherein the one or more processors execute the instructions to:

detect a failed mmWave link between the mmWave UE and a first mmWave transmission point (TP) serving the mmWave UE, and based thereon:

send a cloud cell reformation request,

receive information about a second mmWave TP and a third mmWave TP, and

establish a reformed cloud cell with the second mmWave TP and the third mmWave TP, where a data connection is established with the third mmWave TP and at least a control connection is established with the second mmWave TP,

send a beam-formed random access channel (RACH) to the second mmWave TP,

receive a first beam-formed RACH response (RAR) from the second mmWave TP, thereby forming the control connection with the second mmWave TP,

receive a second beam-formed RAR from the third mmWave TP,

send, to the second mmWave TP, information about the beam-formed RARs, and

receive, from the second mmWave TP, information about transmission parameters of a mmWave link with the reformed cloud cell.

12. The mmWave UE of claim 11, wherein the one or more processors further execute the instructions to send a mmWave link failure report when the failed mmWave link is detected.

13. The mmWave UE of claim 11, wherein the one or more processors further execute the instructions to establish a cloud cell with at least the first mmWave TP prior to detecting the failed mmWave link.

14. A central controller comprising:

a non-transitory memory storage comprising instructions; and

one or more processors in communication with the memory storage, wherein the one or more processors execute the instructions to:

receive a millimeter wave (mmWave) link failure report from a mmWave user equipment (UE), the mmWave link failure report reporting failure of a mmWave link between the mmWave UE and a first mmWave TP,

receive a cloud cell reformation request from the mmWave UE,

receive information about beam-formed random access channel responses (RARs) received by the mmWave UE,

select a second mmWave transmission point (TP) and a third mmWave TP from a plurality of mmWave TPs, wherein selecting the second mmWave TP and the third mmWave TP is in accordance with mmWave TP capability information and mmWave TP load information,

prepare the second mmWave TP and the third mmWave TP for communications with the mmWave UE, and

send information about the second mmWave TP and the third mmWave TP to the mmWave UE.

15. The central controller of claim 14, wherein the one or more processors further execute the instructions to send communications beam information to the second mmWave TP and the third mmWave TP.

16. The central controller of claim 14, wherein the one or more processors further execute the instructions to receive the mmWave TP capability information and the mmWave TP load information from the plurality of mmWave TPs prior to selecting the second mmWave TP and the third mmWave TP.

17. The central controller of claim 14, wherein the second mmWave TP and the third mmWave TP are also selected in accordance with information about a cloud cell associated with the mmWave link, wherein the cloud cell includes the first mmWave TP.

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